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THE CANADIAN/GERMAN COAL SLURRY PIPELINE TECHNICAL WORKSHOP

Proceedings

Edmonton, September 27-28, 1982

Sponsored by
Transportation
Development Centre
and
Alberta Economic
Development

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PROCEEDINGS

of the

THE CANADIAN/GERMAN COAL SLURRY PIPELINE TECHNICAL WORKSHOP

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Edmonton, Alberta, Canada

September 27-28, 1982

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PREFACE

The Canadian/German Coal Slurry Pipeline Workshop was two days of informal presentations on selected topics in slurry research. There was no verbatim record of the sessions and, for several topics, no formal papers were presented. If papers were available, they have been included for reference purposes. If no paper was available, a general summary of the presentation has been included instead. Questions and comments of general interest have also been summarized. Any errors or omissions are, with regret, the responsibility of the editors.

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17 Abstract

The Canadian/German Coal Slurry Pipeline Technical Workshop was held in Edmonton, Alberta, September 27 and 28, 1983. The twenty papers presented on selected topics in slurry research have been put together in these proceedings. Among the subjects discussed were the following: methanol as a carrier, hydraulic capsules, dense coal slurries, selection of slurry pumps, problems in degradation and separation of solids and environmental evaluation.

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17. Résumé

L'atelier canado/allemand sur le transport du charbon par conduites a eu lieu à Edmonton, Alberta, les 27 et 28 septembre 1982. Les vingt communications présentées sur des sujets sélectionnés dans le domaine du transport du charbon en suspension ont été assemblées et sont présentées dans le présent rapport. De nombreux sujets ont été traités au cours de l'atelier, entre autres: le méthanol comme véhicule du charbon, le transport par capsules hydrauliques, le charbon en solution épaisse, la sélection de pompes à charbon en solution, les problèmes reliés à la dégradation et la séparation des particules de charbon, l'évaluation environnementale.

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MORNING SESSION

OPENING REMARKS

Mr. J.J.O. Gravel, Transport Canada, called the workshop to order and introduced the members of the delegation from the Federal Republic of Germany. Following these introductions, Mr. Ken Broadfoot and Mr. Wilf Danzinger of Alberta Economic Development welcomed the FRG delegates and other participants on behalf of the Province of Alberta. Herr Professor Weidenroth and Herr Fiseni thanked the Canadian delegates for their hospitality and expressed their hopes for a productive exchange.

A slide presentation on Alberta was presented by Alberta Economic Development.

Aude: Comments on Recent Developments in the United States

Eminent domain legislation allowing pipeline interests to acquire right-of-way is currently working its way through the federal government. The legislation is opposed by the United States railways who see slurry pipelines as undesirable competition. The legislation is currently at a critical phase. There is a good chance it will be passed in the next few months.

Slurry pipelines used to be a special issue. Now they are supported by a broad range of consumer groups and utilities because they would lower the cost of energy.

The Energy Transportation Systems Inc. (ETSI) slurry pipeline has been in the works for ten years. In the next few months it will probably go or be abandoned. The project managers have solved the right-of-way problem, acquired water rights, and will not be affected by the pending eminent domain legislation. During the next few weeks they will be submitting proposals to utilities, on which the utilities must act so the project can proceed.

If the ETSI pipeline proceeds to construction and the eminent domain legislation is passed, this would have a large and positive impact on slurry pipelining in the United States. If either of these does not happen, slurry pipelining will receive a large setback.

Coal Transportation - The Economic Alternatives

Thomas C. Aude and Terry L. Thompson, Pipeline Systems Incorporated, Orinda, CA, U.S.A.

Introduction

The objective of this paper is to present, in generalized form, the results of economic studies of coal transportation. It can be determined intuitively that certain modes of transporting coal are appropriate to specific transportation requirements. We will define in this paper, at least in a general way, the boundaries of appropriateness for the transportation of coal by highway, truck, new railroad, unit train over existing tracks, and slurry pipeline.

The evaluations will be primarily economic based on estimates of today's cost of transportation and projection of the effects of inflation over the life of a transportation requirement. The environmental issues, energy efficiency, eminent domain and water supply will also be generally discussed.

The development of coal transportation requirements over the past century has progressed from very low volume short distance movements. Since that time the uses of coal have evolved from residential space heating, industry, and railroad steam engines, through heavy industry and finally to large centralized boilers for steam driven electric generators. At the same time transportation requirements have evolved from local distribution of small quantities of coal through area distribution requirements of somewhat larger quantities and finally massive movements of western subbituminous coal to mid-western power plants. This evolution of the length and volume of coal movements is in part due to depletion of high quality reserves near demand areas, more stringent sulphur emission control requirements and the increasing cost of labor to recover eastern coals. It will be shown that factors such as the coal tonnage to be moved, the length of the movement, the period of the transportation requirement, and the existing road or railroad infrastructure play a fundamental role in selection of the transportation mode.

The setting for this evaluation is the United States west of the Mississippi River with particular emphasis on the Rocky Mountain area coal reserves. The estimates presented are generalized from specific evaluations made over the past twelve months. The estimates, of course, are only indicative, intended to demonstrate the relationship rather than provide dollar estimates that would apply to specific areas.

Alternatives

The four alternative modes discussed are truck, new railroad, unit train, and pipeline. This section gives a general description of each alternative including the existing experience and common applications.

Truck

In this evaluation the term truck transportation is used to describe highway vehicles rather than the mine haul trucks commonly found in open pit mining applications. In this case the trucks are assumed to use existing public roads with only a minor amount of new road required to connect the mine to the existing network. The fuel and users taxes paid by the trucking operation are assumed to provide the revenue necessary for maintenance of the roadway by government authorities.

A major advantage of truck transportation is the short lead time required to start the operation since delivery of over-the-road trucks is short and no appreciable construction period is required. A further advantage is the ability to discontinue the trucking operation after a short period of time and without advance notice, with manageable financial impact.

Trucks are, by their very nature, a relatively low volume method of transportation. A 25-ton payload is about the maximum that can be transported over the public roads in most areas. This leads to a high labor intensity in this transportation mode since one operator is required to move 25 tons of coal. For orientation purposes we might say that a "typical" truck could haul about 15,000 tons per year a distance of less than 100 miles.

Another major advantage of truck movement is the lack of the requirement for environmental permits before the operation can start. This is not to say that scrutiny of the use of truck transportation would not become a part of environmental reviews of a mine development, but the act of starting the trucking operation itself does not require specific permits.

Depending on the number of trucks involved, the social and environmental impacts of the truck movement, although noticeable, are not severe. They are noticeable primarily as the result of increased traffic over the roads used by the movement.

New Railroad

New mines, particularly for western coal, may be remote from the existing railroad or highway infrastructure, in which case construction of a new railroad to connect the mine to the existing railroad network would then be considered. Since a significant investment would be required in the road bed and track, some assurance would be required that sufficient tonnage would move over the new track to support its amortization at a reasonable rate. A large new mine would, in most cases, be capable of producing sufficient tonnage to support a new railroad, provided contracts for sale of the minable coal reserves were made.

The timing of development of a new railroad system is on the order of that required for the mine development. Some environmental reviews and permits would no doubt be required, but these could be acquired in the same time frame as permits for the mine. For talking purposes, the scale of such a transportation system would probably be less than 200 miles in length with a capacity up to at least 20 million tons per year. It is assumed that unit trains are moved over a track system built to the prevailing United States standards for gauge, grade and weight of rail.

From a social and environmental standpoint, the new railroad will be a new linear surface use with the attendant interruptions to other surface uses that exist or are contemplated, particularly in a perpendicular direction to the railroad track. In some cases fairly heavy civil works, that is, deep cuts and fills or bridge structures, may be required.

Unit Train

As used in this evaluation, a unit train concept is presumed to use the existing railroad network with no start-up expenses beyond those involved in putting the rolling stock into operation. It is assumed that the maintenance of the existing road bed and replacement of rail is part of the tariff charged by the railroad operator for the movement.

A typical unit train with 110 cars, each of 100 tons capacity, can move 1.5 million tons per year over a distance of somewhat less than 1,500 miles. The major time constraint is initiating the operation is acquisition of the rolling stock. The constraint on terminating the movement is sale of the rolling stock. Although both these activities are considerably greater in proportion than for a truck movement, they still allow a fairly large degree of flexibility to change or terminate the movement to meet future conditions.

No special permits are required to initiate the unit train movement over existing tracks, although at some stage the increased traffic over western railroads could become an environmental issue. This could result in possible impacts on the transportation costs resulting from the railroads reacting to concerns of those along the length of the railroad.

Pipeline

A coal slurry pipeline as used in this discussion would be of the conventional design as demonstrated in the Black Mesa system. It would be built for a specific transportation requirement.

Pipelines are a capital intensive mode of transportation requiring a several year period for permitting, design and construction. An assurance of utilization at a predictable rate over a sufficiently long period of time to amortize the investment cost is needed to acquire financing. The major advantage resulting from selection of a slurry pipeline is the predictability of transportation costs due to their low variable cost content and the anticipation of only moderate cost increases even during periods of high inflation.

Pipelines do require water or some other liquid carrying medium; about 250 gallons of water per ton of coal are required to make up the slurry.

Characteristics

The characteristics of the four transportation modes are summarized on Table 1. One aspect of the comparison must be noted and that is the energy requirement. Energy requirements are shown on Table 1 related to ton-miles. When making a direct comparison, it is important to note that the transport distance will not be the same for the various modes of transportation.

TABLE 1
CHARACTERISTICS

Characteristic	Truck	New Rail	Unit Train	Pipeline
Availability	Public roads exist near most sites	Built to suit requirement	Use existing track	Built to suit requirements
Lead Time Required				
EIS & permits	Nil	1-2 years	Nil	1-2 years
Construction	Nil	2-3 years	Car delivery	2-3 years
Minimum Shipment Size	25 tons per load	100 tons per car	11,000 tons per train	Continuous
Typical Annual Capacity	15,000 tons per truck	100,000 tons per car	1.5 million tons per train	5-25 million tons per year
Typical Distance	Less than 100 miles	Less than 200 miles	Less than 1500 miles	Less than 2000 miles
Required Duration	Nil, trucks resaleable	15-25 years	Short, cars can be sold	15-25 years
Social and Environmental Effects	Increased road traffic	Linear surface use, heavy cuts and fills	Increased railroad traffic	During construction period
Energy Efficiency*	7300 BTU/T-mi	488 BTU/T-mi	488 BTU/T-mi	608 BTU/T-mi
Water Requirements	Nil	Nil	Nil	250 gallons/ton

*Note: lengths for rail are normally longer than pipeline due to grade requirements.

Current Costs

Capital and operating costs for the transportation alternatives were developed based on recent in-house estimates and published information for the various modes. They are adjusted to mid-1981 cost levels. They include allowances for contingencies and the cost of engineering, permitting, and managing the construction of the projects where appropriate.

Transportation rates are based on current calculations for the truck and pipeline cases and published tariffs for the railroad cases. In evaluating the unit cost of capital it was assumed that 75% of the capital costs were funded by debt at an interest rate of 12% per year and the remaining 25% is funded by equity which earned a 15% after-tax return on original investment. Interest expenses were levelized over the period of the investment. The pipeline and railroad track investments were depreciated over a 30-year period, while rail cars were assumed to have a life of 15 years and trucks a life of 7 years.

Pipeline

Figure 1 shows the projected transportation costs for a coal slurry pipeline as a function of annual throughput and length. Also shown is the breakdown of these costs into the components of water, assumed to cost $1,000 per acre foot, slurry preparation, *dewatering and pipeline. In the case of* a 1,000-mile, 25 million ton-per-year pipeline, the transportation costs are distributed as follows:

• Water	4%
• Slurry Preparation	12%
• Dewatering	20%
• Pipeline	64%
TOTAL	100%

Figure 1 illustrates the economies of scale of slurry pipelines. For instance, increasing the throughput from 10 to 25 million tons per year results in a 30% reduction of the unit transportation cost for a 7,000 mile pipeline. Figure 1 also illustrates the weight of the non-pipeline elements in the overall transportation costs for slurry pipeline. As shown above, the non-length related components make up 36% of the transportation costs for a 1,000-mile system. For a 500-mile system the non-pipeline components of the cost make up 53% of the total transportation cost.

Unit Train

The unit train rates shown on Figure 2 for a 1,000-mile distance were developed from published tariffs effective in mid-1981 for movement of coal from the Powder River Basin eastward to the Great Lakes area in railroad owned cars. The average rate used was 1.5 cents per ton mile. This was based on four tariffs for movements ranging from 800 to 1,280 miles on a single railroad.

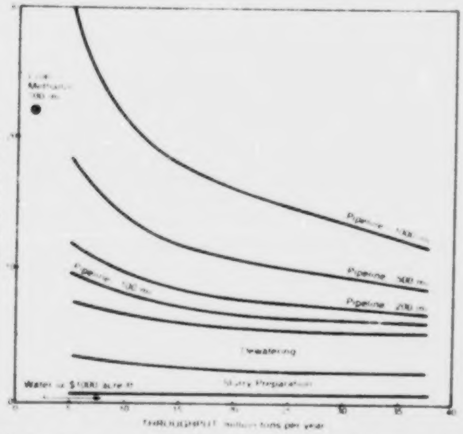


Figure 1 Slurry Pipeline Rates

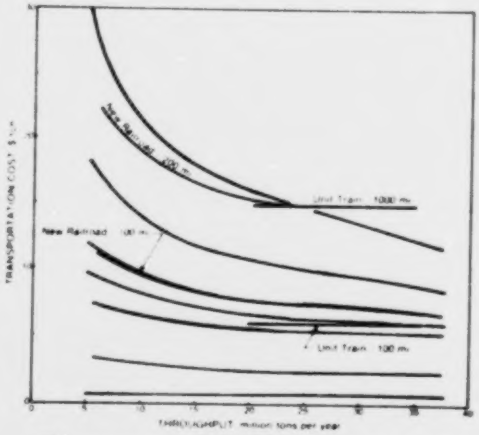


Figure 2 Railroad Rates

A calculation was made of the proportion of a 1,000-mile movement's tariff attributable to the cost of the cars and their operation. That calculation indicated that the cars represented about 3.5% of the overall transportation cost.

The line on Figure 2 for unit trains at 100-mile distances is based on the average of 16-unit train tariffs for movements in railroad owned cars over distances ranging from 35 to 120 miles. This average tariff for those movements was 6.15 cents per ton mile on a mid-1981 basis.

New Railroad

Also shown on Figure 2 are curves for the transportation cost over new railroads of 100- or 200-mile lengths. These costs are significantly higher than the unit train costs since the full cost of construction of the railroad must be borne by the coal movement. These costs were based on recent estimates and average about 1.7 million dollars per mile for construction of the railroad. The capital charges for this investment were added to the short distance unit train tariff of 6.15 cents per ton mile to project the cost curves.

Trucks

The highway truck rates shown on Figure 3 were built up from recent estimates of the capital cost of trucks and associated support facilities. As mentioned earlier, a truck life of 7 years was used, which results in an overall capital charge of 28% when the previously discussed parameters are used. Truck operating costs include diesel fuel, labor, tires, lubricants, supplies and regular schedule of overhaul of the trucks. The average 1981 unit transportation cost for the truck case was 8.2 cents per ton mile, which is somewhat below the rule of thumb figure of 10 cents per ton mile.

COST INFLATION

The transportation costs discussed above were projected forward in time on the assumptions of 5% per year inflation of the variable portion of the transportation costs. Although the 5% per year assumption seems quite modest in today's environment, it was felt that current inflation rates would not persist over the life of the study. Two cases were evaluated. One is transportation of 25 million tons per year for 1,000 miles and the second for transportation of 5 million tons per year for 100 miles.

A major simplifying assumption in making comparisons is that the transport distance is the same for the different modes. This would generally not be the case, particularly when existing roads or rails are compared to new pipeline or rail. It would also be expected that a new pipeline would be shorter than a new railroad, since pipelines' grade restrictions are much higher. Generally, pipeline distances will be shorter than the other modes; however, that fact is not considered in the following comparisons.

Figure 4 shows the results of rate inflation for the 25 million ton per year, 1,000-mile case. As can be seen by inspection of Figure 3, only unit train or pipeline were the reasonable choices for this transportation requirement. Also, note that the initial transportation costs were approximately equal for unit train and pipeline. Figure 4 shows that over the 30-year study period the unit train rates increase to the extent that in the final year the pipeline rate is 54% of the unit train rate. This results simply from the fact that for this evaluation 74% of the pipeline costs were capital related fixed costs, while only 25% of the rail costs were fixed. This rail cost figure is somewhat more favorable than the commonly used figure of 80% variable costs for unit train operations. The figure used here recognized the fixed cost characteristics of the unit train car investments.

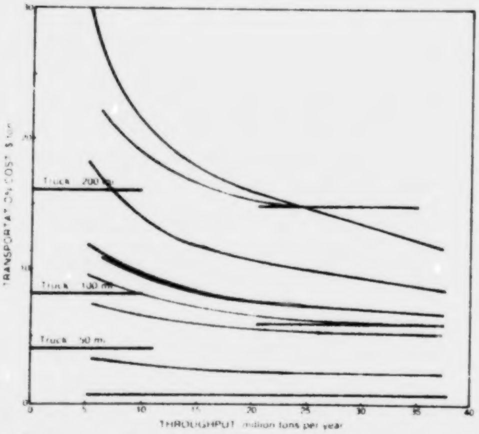


Figure 3 Truck Rates

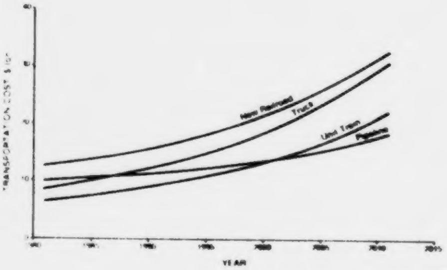


Figure 4 Rate Inflation

The second rate inflation case for transportation of 5 million tons per year, a distance of 100 miles, was developed based on the fixed and variable cost distribution shown in Table 2. Figure 5 was based on the initial cost shown on Figure 3 and the cost breakdown shown on Table 2. Initially the unit train is the lowest price alternative, assuming that the track system is in existence and of course, assuming that the length of the track is 100 miles. If track did not exist, the next lowest alternative, on an initial cost basis, is trucks operating over existing highway.

TABLE 2
TRANSPORTATION COST BREAKDOWN
5 MTA - 100 miles

	Fixed	**Variable**
Pipeline	74%	26%
Unit Train	21%	79%
New Railroad	50%	50%
Truck	16%	84%

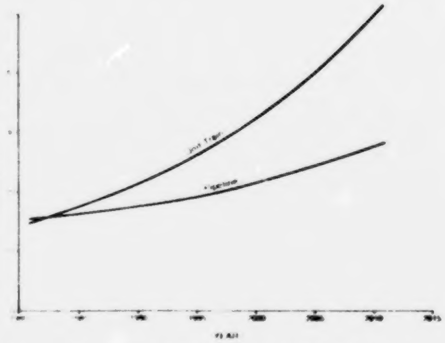


Figure 5 Rate Escalation

If no railroad or highway length exists between the mine and the 100-mile distant terminal point, then a slurry pipeline would be chosen in favor of a new railroad. Even if roads exist, the pipeline would be chosen if the movement would continue for the long-term. In an evaluation over the long-term, where railroad trackage existed the unit train would be chosen.

The generalized comparison shows, based on total discounted costs, using a 10% discount factor, that for a long term movement slurry pipeline is the appropriate choice over unit trains on existing railroad tracks if throughput is above 12 mta (and 100 miles). If track does not exist, a slurry pipeline should be selected over a new railroad if the distance is over 65 miles and throughput over 5 mta. The coal industry has arrived at the point where many movements are appropriate to pipeline transportation.

CONCLUSION

The economic analysis presented in this paper demonstrates what can be observed in a study of the history of the development of coal transportation. That is, that there is an appropriate mode of transportation of coal for each specific set of distance, volume, and duration circumstances. We can observe the historical development of coal transportation from initial small quantities over short distances carried by wagons or trucks through the development of the nation's railroad infrastructure and unit train movements. If the above analysis is correct, we are on the threshold of entering a period of development of high volume, long distance coal slurry pipelines dedicated to movement from specific mines to specific power plants over the lives of those facilities.

This movement toward slurry pipeline transportation is being accelerated by the recent deregulation of railroad tariffs. Railroad tariffs are currently in a phase of rapid upward adjustment and their levels, when they stabilize with general economic movements, are expected to be considerably higher than today. This upward adjustment of unit train rates was not considered in this evaluation and would tend to enlarge the range of volumes and distances appropriate to selection of slurry pipeline transportation.

Development of the pipeline infrastructure will not displace the other transportation modes. This analysis shows that conventional slurry pipelines are appropriate to long distance, large volume, long duration movements, whereas other modes are appropriate to other segements of the total coal transportation market.

Questions on Paper by Aude

Q: It will cost $100 million just for ETSI water rights?

A: The $100 million includes water rights and right-of-way costs.

Q: Is there an advantage to utilizing slurry pipelines to transport coal over the mountains to the west coast?

A: Yes. Rail requires a 1 1/2 per cent grade, while a slurry pipeline can operate with a 16 per cent grade. The rail line goes around the mountains, while the pipeline goes over them. The pipeline takes shorter, more direct routes. This means less earthwork is required. We have also found that the heat generated by friction maintains the slurry temperature, and prevents it from freezing. Freezing is not as big a problem as it initially appeared.

Q: Does the $3.00 per ton for dewatering include the heat required?

A: Yes. It includes dewatering and thermal drying. It was agreed that the cost was probably low.

Q: What share of the 32 per cent of total cost of preparation and dewatering was dewatering costs?

A: 20 per cent of the costs were dewatering.

Klose: Comments on Coal Slurry Economics in Germany

Herr Klose presented the results of a study carried out by his company in FRG where they evaluated slurry pipelines as a means of moving iron ore and coal from Williamhaven and Hamburg to their steel producing facility.

Rail costs have been very high during the last few years, and this has caused us to investigate slurry pipeline economics. We looked at the cost of building a slurry pipeline to move 3 million tonnes of coking coal 250 kilometres to the coast. The slurry was between 53 and

54 per cent coal by weight. We found that, if the slurry terminal was located by a shallow harbour, shiploading costs were greater. The pipeline system would require an investment of 200 million marks on a 1980 basis. Compared with rail costs, which were 100 per cent, barging costs were 103.6 per cent, and pipeline costs were 83.2 per cent. We forecasted these costs over the next 20 years. An iron ore pipeline was also costed.

Questions on Klose's Presentation

Q: Could the costs from this study be made available?

A: They are proprietary.

Q: Do the 200 million marks include the cost of research?

A: No.

Q: What about the cost of water treatment?

A: (Aude): Environmental impact studies cost ETSI about $6 million. This included the cost of the environmental impact statement, and the permits to cross federal lands. The environmental costs were insignificant related to the total cost of the project. The water treatment costs were quite trivial from a decision standpoint.

A: (Klose): The slurry water could be used for process water instead of being disposed of directly.

Q: Did you look at the economics of transporting American coal by barge?

A: (Aude): Yes. Barging coal down the Mississippi River would be the cheapest alternative to the slurry pipeline.

Q: What grain size were you assuming in your slurry economies?

A: (Aude): We used demonstrated Black Mesa pipeline technology - i.e., fine coal slurry.

Fiseni: Consideration of Pipelines for Solids as a Link in Transport Chains

Consideration of Pipelines for Solids as a Link in Transport Chains

Felix Fiseni, Technischer Uberwachungs - Verein Rheinland e.V., Projecktbegleitung Guterverkehr und Transportketten, Germany

Pipeline transportation of coal represents a new transport technology as an alternative to traditional bulk transportation by rail or inland waterways. Pipelines have already been used for some time in short-distance transport of sludges, in coal screening and dredging, and also in long-distance transport of ores and coal. It would appear too that it has proved to be an economical system as many more new projects have been planned.

However, the question of improving the economy of technical systems is always being raised and, of course, this also applies to this new technology; and influencing the economy, there is also the question of technological innovations. Above all we must ask about the need for such a transport system.

In this discussion I shall only be referring to coal as material to be transported.

If we consider the flow of transport of the primary energy carriers, coal and oil, we find rather different situations. In contrast to oil, the main mining countries of coal are also the main consumers of primary energies or, if we look at China, will become so in future. Among other things, this had led to the world coal trade remaining on a low scale. Forecasts on future developments of the world coal trade as well as on energy requirement are subject to increasing uncertainties. The main influencing factors are

- the general developments in the world economy
- the substitution of oil by coal and
- improved energy-saving production methods.

I should like to mention some forecasts on coal requirement which generally indicate an expansion of coal trade.

- According to Professor Bahke the world coal trade will increase from 220 million tons in 1978 to a thousand million tons in the year 2000.

- For the Federal Republic of Germany coal imports are anticipated to be five times as high, increasing from the present 7.4 million tons (the 1981 value) to 40 to 60 million tons per year.
- According to the forecasts of the energy consulting firm, ICF Inc, the export volume of power plant coal by the main coal mining countries will increase by a factor of three from 1980 to 1990 to 290 million tons and by 1995 it will be almost five times as high at 450 million tons. This can be seen in the diagram.

Despite the generally optimistic forecasts on energy requirement - even for the consumption of primary energies in which hard coal, for instance in Germany, accounts for a proportion of 25% in the generation of electricity - more recent surveys are assuming that the absolute increases will not be as high as those just mentioned.

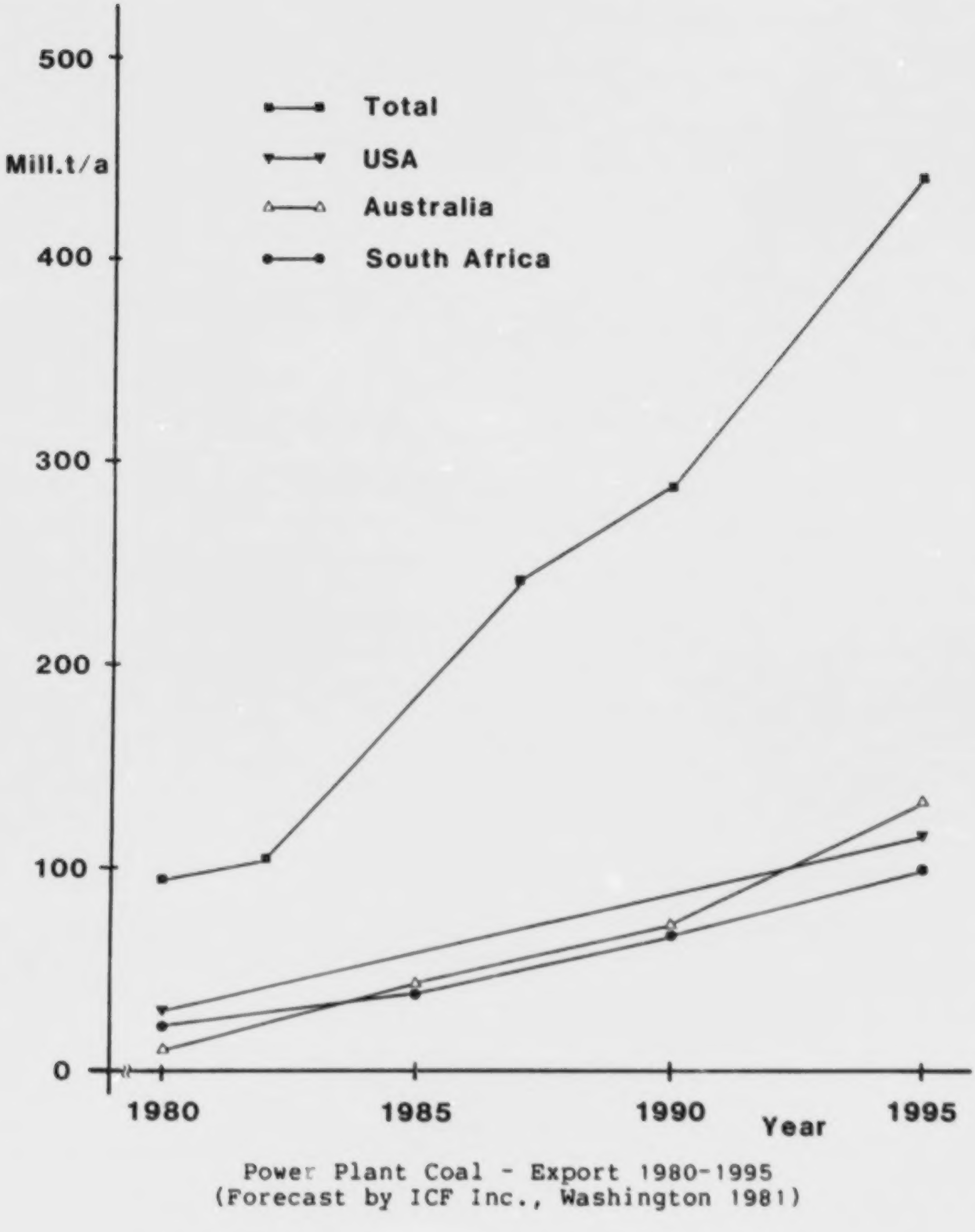
But the absolute figures are not the deciding factor, as the energy-saving measures which will have to be introduced anyway are independent of these. Still we must assume that there will be an increase and for this additional volume the most economical means of transport must be investigated.

If we consider the geography of the main mining locations in the world, with the assumption of large quantities of export material (besides domestic requirement), it is true for the USSR, for China, Australia, USA and Canada that great distances have to be overcome to transport the material to the coasts. And in some cases there is not even a conventional transport infrastructure.

It is here that we see a potential starting point for pipeline transport, and in many of these countries this is already being included in their future infrastructure plans.

In order to meet future requirement, also using pipeline technology, this technology must be further developed within the context of a total transport system.

When we consider the transport route for coal from its extraction up to its consumption, it is clear at the latest in handling at the coast that before it can continue as conventional sea transport on bulk freighters, the coal must undergo a dewatering process and, in the case of it being further transferred to a pipeline transport system, it must again be processed to an optimum slurry mixture. A large proportion of the operating costs with a coal-slurry

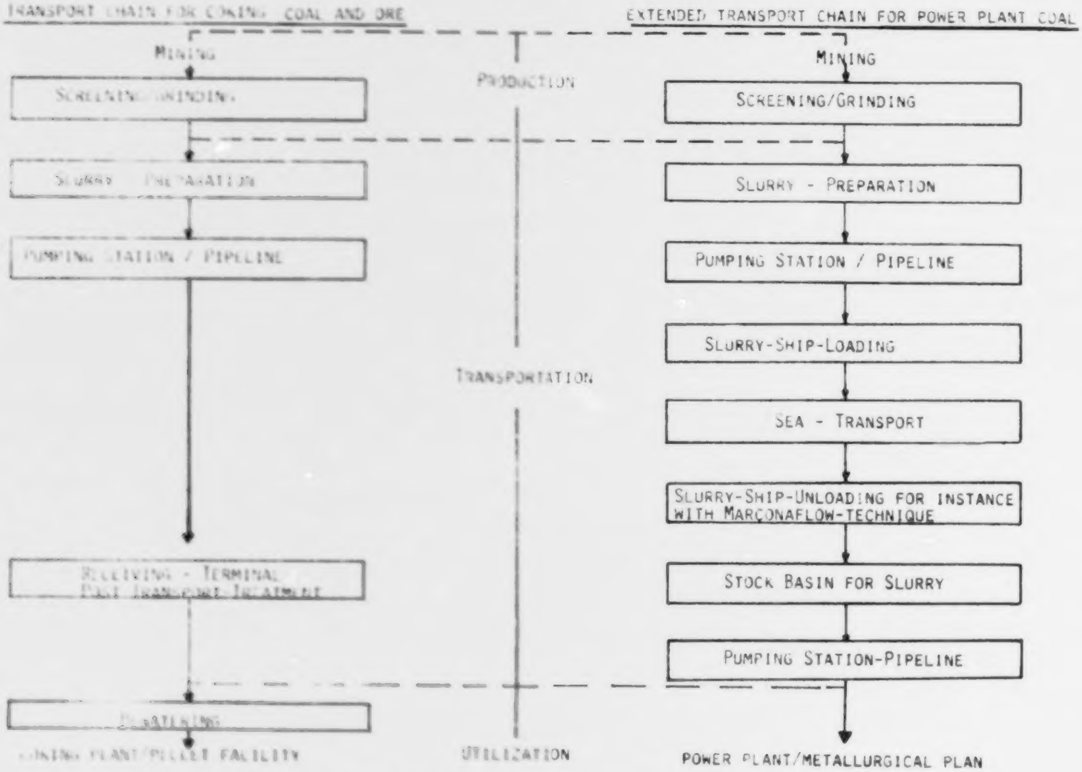


Power Plant Coal - Export 1980-1995
(Forecast by ICF Inc., Washington 1981)

pipeline arises with the preparation and dewatering of the coal. Therefore it is these links in the transport chain which must be given the greatest emphasis in the overall planning. This is also one of the reasons why the tendency with pipeline transport of coal is leading to coarse coal.

Though coarse coal means economic advantages on the transport side - especially relating to the dewatering - on the consumer side (power plants) for example, other requirements are being placed on a limitation of the grain size of the coal.

Thus it is important when considering this kind of transport system that in future the individual links in the transport chain are adapted to one another according to their respective conditions. Here we must begin to see the pipeline not as the only link between the producer and the consumer, but as a part of the total system. Let us have a look at a diagram of an extended transport chain.


TRANSPORT CHAIN FOR COKING COAL AND ORE
EXTENDED TRANSPORT CHAIN FOR POWER PLANT COAL
MINING
PRODUCTION
MINING
SCREENING/GRINDING
SCREENING/GRINDING
SLURRY - PREPARATION
SLURRY - PREPARATION
PUMPING STATION / PIPELINE
PUMPING STATION / PIPELINE
SLURRY-SHIP-LOADING
TRANSPORTATION
SEA - TRANSPORT
SLURRY-SHIP-UNLOADING FOR INSTANCE WITH MARCONAFLOW-TECHNIQUE
RECEIVING - TERMINAL
POST TRANSPORT TREATMENT
STOCK BASIN FOR SLURRY
PUMPING STATION-PIPELINE
DEWATERING
COKING PLANT/PELLET FACILITY
UTILIZATION
POWER PLANT/METALLURGICAL PLAN

System of pipeline transportation for solids

The aim of a research program is to study this uninterrupted transport chain so that at a later stage a joint project with wharfs, handling companies and power plant constructors and operators can be conducted to develop the sectors of transport, handling, treatment and final processing of highly-concentrated coal slurry up to operation maturity.

A more comprehensive concept for a research program should treat the subject of the transport chain as a whole. This would mean that the following research work would be necessary:

1. Inclusion of suitable extraction procedures in respect of long-distance transport (hydromechanical mining, partial coal liquefaction, for example, methanol processing, and subsequent mixture with the remaining coal) and the associated treatment techniques.

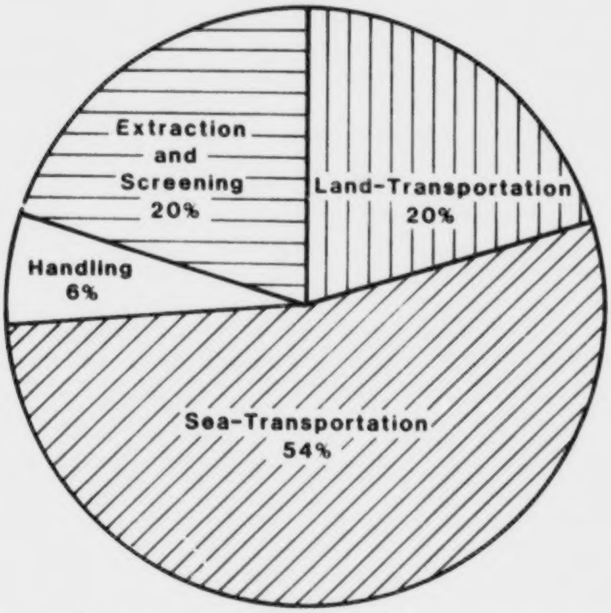
2. Investigation of simplified handling procedures for slurry; off-shore loading techniques contrasted with those used so far comprising port-bound expensive crane, conveying and suction techniques; adaptation of the existing transfer procedures to a solid-liquid mixture such as dense coal.

3. Integration of existing bulk transport systems, such as oil tankers, for highly-concentrated coal slurry or, for example, utilization of the present inland waterways to facilitate the construction of a network of slurry pipelines via distribution points (inland ports).

4. Adaptation of the coal-liquid mixture to the conditions of the consumers (power plants) in respect of viscosity, mixing ratio and the possibility of direct combustion, stability, loss of efficiency through moisture, etc.

Here we must realize that an important part of the export of coal is the loading and unloading of the ship and the sea transport which must be incorporated in the overall concept.

The costs to be considered in conjunction with the sea transport can be seen from the figure comparing the individual shares of the transport costs. These are the costs of handling and transport relative to conventional bulk freighters. Just a small increase in percentage of remaining moisture means additional costs for the shipping which influence the total transport costs to such an extent that normal pipeline systems are no longer economical. The cost proportion for sea transport within the integrated transport system from extraction up to consumption can be between 50 and 60% (see figure).



Classification of Costs in Slurry Pipeline Transportation
(Shell-Study, Breuer/Huberts 1976)

Reducing this high cost proportion is a task which could be resolved by a new development in handling technology, namely using off-shore slurry loading facilities. For the south and east coasts of the USA and for the east coast of Australia whose ports do not have sufficient water depth and also for completely new sites of coal export ports, this technology, namely loading the more economical large bulk carriers from off-shore loading stations, would be the best possible solution and we can draw on the experience gained with ore-loading facilities in New Zealand for their development.

This technology can also benefit from what is being investigated at present as the latest development for slurry transport in pipelines, namely dense coal as a specially treated suspension of grain sizes from 0-0.3 mm with a solid proportion of 70-80%. In this case, dewatering is totally unncecessary; the transfer to ships can be carried out in the same way as for oil tankers with only slight technical alterations, so conventional tankers can be used. Apart from this, the consumer (power plant) will be able to fire the coal directly in this slurry mixture. The advantages of this dense coal are obvious which is why it is necessary to promote investigations into these highly-concentrated suspensions.

The investigations into the technical realization of dense coal will have to be followed by economic considerations. No generally valid statements can be made on the slurry transport of coal since the physical and chemical properties of each type of coal react differently during transport and the energy generator and consumer conditions vary too. This makes it even more important not only to study the individual components separately, but to consider them from the viewpoint of an integrated transport chain.

Initial approaches to these problems seem to have been done in many countries. This should be expanded to a concentration of the research activities and perhaps to continue in international cooperation on an industrial as well as on a scientific level.

Rabb and Bassett: Alberta Coal Slurry Pipeline Feasibility Study 1981 - An Economic Assessment Opposite Rail Transportation

Alberta Coal Slurry Pipeline Feasibility Study 1981
An Economic Assessment Opposite Rail Transportation

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Ray C. Bassett, Director, Economic and Management Studies, Transportation Services Branch, Alberta Economic Development, Edmonton, Alberta

ABSTRACT

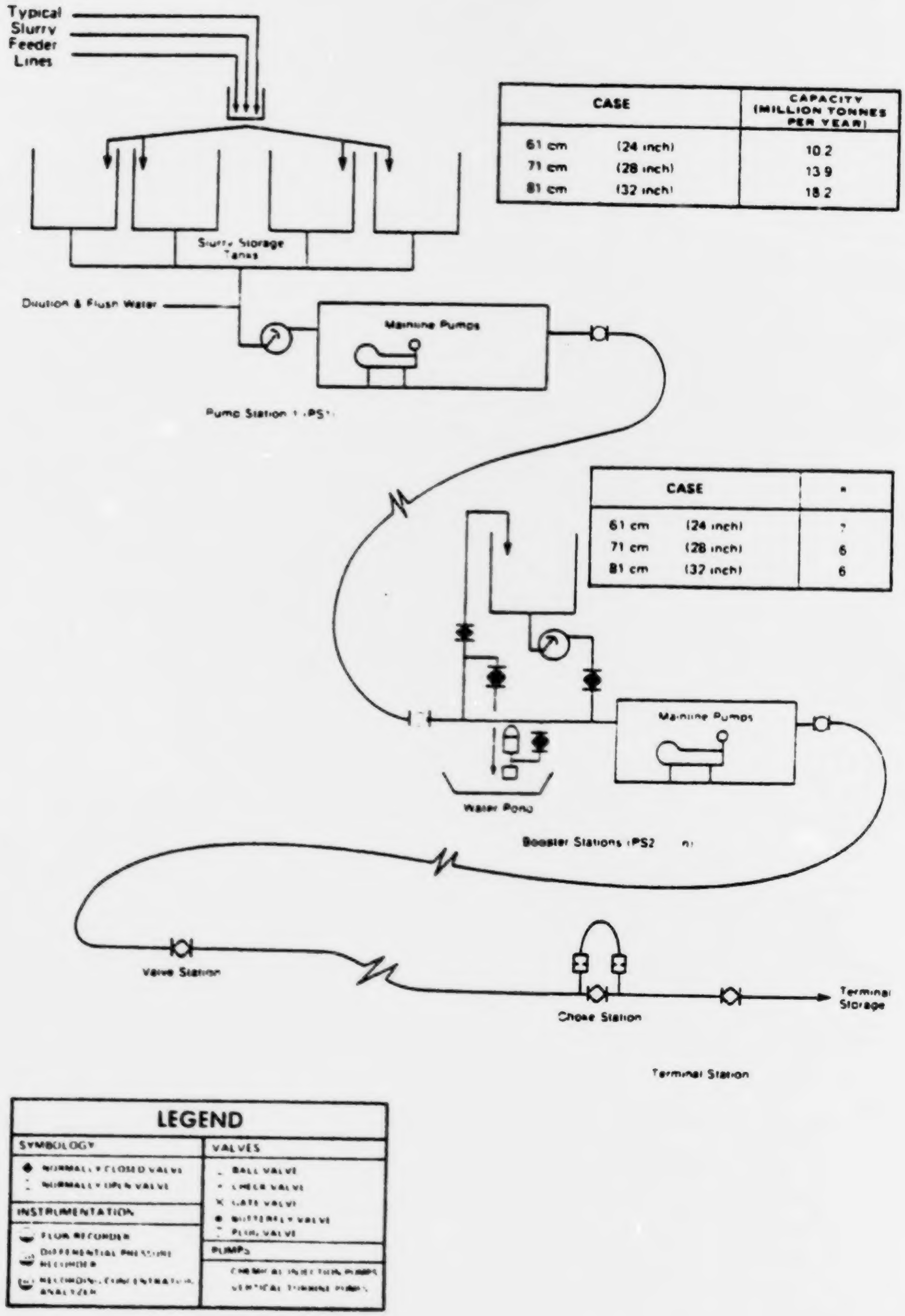
In 1981, the Alberta Government Departments of Economic Development and Energy and Natural Resources retained a consortium of engineering companies headed by Fluor Canada Ltd. to study the feasibility of transporting Western Canadian thermal coal via slurry pipeline to a Canadian west coast port site. This paper reviews the design criteria, the pipeline route, the port site, and the economic feasibility of a coal slurry pipeline as a competitive mode to rail. The analysis examines the capital and operating costs of the rail alternative and compares them to the pipeline. Through a detailed analysis of the economic sensitivities of both modes, the paper identifies the conditions necessary for a pipeline to be competitive with a unit train operation.

Coal shippers in the land-locked Province of Alberta have always recognized the importance of an economical and efficient transportation system for moving their coal to Canadian west coast ports. For the most part, export coal moving to overseas markets is captive to the rail mode. In the period from 1970 to 1980, Alberta coal shippers were faced with rail rate increases of over 400 per cent. During this period it became increasingly obvious that if Alberta coal suppliers were to remain competitive in world markets, rate increases of this magnitude could not continue. The most effective way to limit rate increases would be to break the railway's monopoly. Wishing to develop an efficient alternative way to transport Alberta's vast thermal coal reserves to tidewater, the Government of Alberta commissioned a consortium of engineering firms headed by Fluor Canada Ltd. to investigate the technical feasibility and to estimate the cost of transporting between 10.2 and 18.2 million tonnes of thermal coal to the Canadian west coast by slurry pipeline. This study was completed in 1981. The study found it would be technically feasible to construct and operate a 1,032 kilometre coal water slurry pipeline to transport coal from mines located near Coalspur, Alberta, to the Port of Kitimat in British Columbia. This paper outlines the design, operation and cost of this proposed coal slurry pipeline and reviews the economic feasibility of the pipeline compared with a unit train operation.

The Coal Slurry Pipeline System

A schematic representation of the slurry pipeline system is shown in Figure 1. The pipeline system comprises three major components: the main coal preparation plant, the pipeline, and the marine terminal. The main coal preparation plant also includes the slurry feeder pipelines and the water supply system. These facilities would be located near the pipeline's origin at Coalspur, in west central Alberta. The pipeline component also includes the pump stations which would be located at intervals along the pipeline between Coalspur, Alberta, and Kitimat, British Columbia. The marine terminal also includes slurry dewatering facilities and shiploading equipment which would be part of the marine terminal at Kitimat.

Two pipeline systems were designed and costed in the study. In the base case, a pipeline system was designed to transport 10.2 million tonnes of coal per year. In the expanded case, a pipeline system was designed to transport 18.2 million tonnes of coal per year. In both cases, the pipeline was designed to operate for 35 years. The design basis for the pipeline is summarized in Table 1.


Typical
Slurry
Feeder
Lines
Slurry Storage Tanks
Dilution & Flush Water
Mainline Pumps
Pump Station 1 (PS1)
Mainline Pumps
Water Pond
Booster Stations (PS2 … n)
Valve Station
Choke Station
Terminal Storage
Terminal Station
LEGEND
SYMBOLOGY
NORMALLY CLOSED VALVE
NORMALLY OPEN VALVE
INSTRUMENTATION
FLOW RECORDER
DIFFERENTIAL PRESSURE RECORDER
RECORDING CONCENTRATION ANALYZER
VALVES
BALL VALVE
CHECK VALVE
GATE VALVE
BUTTERFLY VALVE
PLUG VALVE
PUMPS
CHEMICAL INJECTION PUMPS
VERTICAL TURBINE PUMPS

CASE		CAPACITY (MILLION TONNES PER YEAR)
61 cm	(24 inch)	10.2
71 cm	(28 inch)	13.9
81 cm	(32 inch)	18.2

CASE		n
61 cm	(24 inch)	7
71 cm	(28 inch)	6
81 cm	(32 inch)	6

Figure 1 Pipeline system block diagram

TABLE 1
DESIGN BASIS FOR COAL SLURRY PIPELINE

Base Case Throughput	10.2 million tonnes per year
Expanded Case Throughput . . .	18.2 million tonnes per year
Design Life	35 years
Port Site	The British Columbia Coast (location of marine terminal and dewatering facilities)
Pipeline Origin	Coalspur, Alberta, Canada (location of central slurry gathering facilities)
Coal Source	5 mine sites within 16 kilometres of Coalspur, Alberta
Operating Schedule	24 hours per day, 364 days per year

Source: Fluor Canada Ltd., Coal Slurry Pipeline Feasibility Study 1981, November 1981

The thermal coal was assumed to originate at 5 mines located within a 16 kilometre radius of Coalspur, Alberta. Slurry preparation plants at each mine site were designed to produce slurried material for pipelining via feeder pipelines to the central slurry collection and preparation plant of Coalspur. At the central slurry plant, all the feeder streams would be blended into a single stream for delivery via the main pipeline to an export terminal located in British Columbia. From here the coal would be dewatered and loaded on ocean going carriers for delivery to foreign markets.

Pipeline Route and Port Site Selection

An elaborate matrix decision process was utilized to identify several potential pipeline corridors to Pacific port sites in British Columbia. The final selection of Kitimat, British Columbia, as the port site and the selection of the pipeline route from Alberta to the west coast fixed the geographic location for the bulk coal transportation system. The candidate pipeline route is shown in Figure 2.

In selecting the pipeline route, existing highway, pipeline and electrical transmission line rights-of-way were taken advantage of wherever possible, especially in environmentally sensitive areas such as Jasper National Park and Mount Robson Provincial Park. The total pipeline length was estimated to be 1,032 kilometres. The port site selected was near Wathlsto Creek, which is about 11 kilometres south of Kitimat, British Columbia. Figure 3 shows the location of the proposed coal slurry port site.

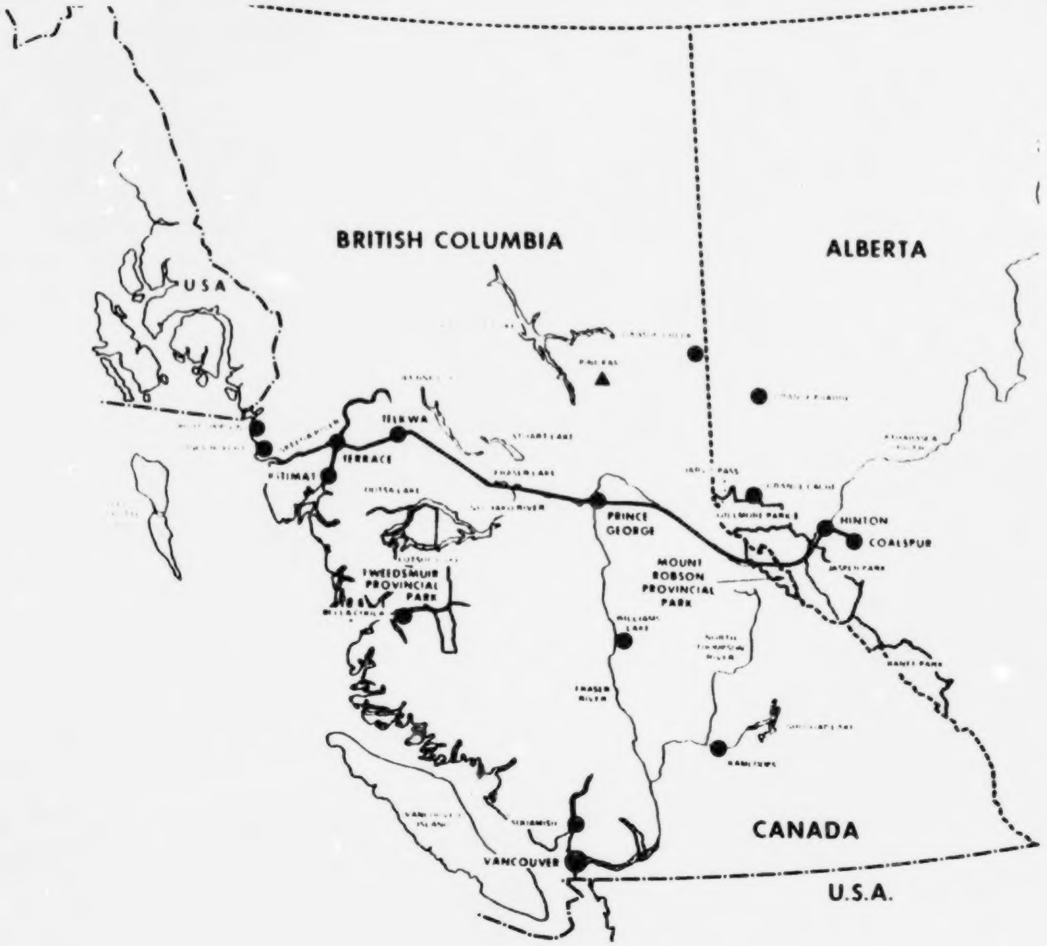
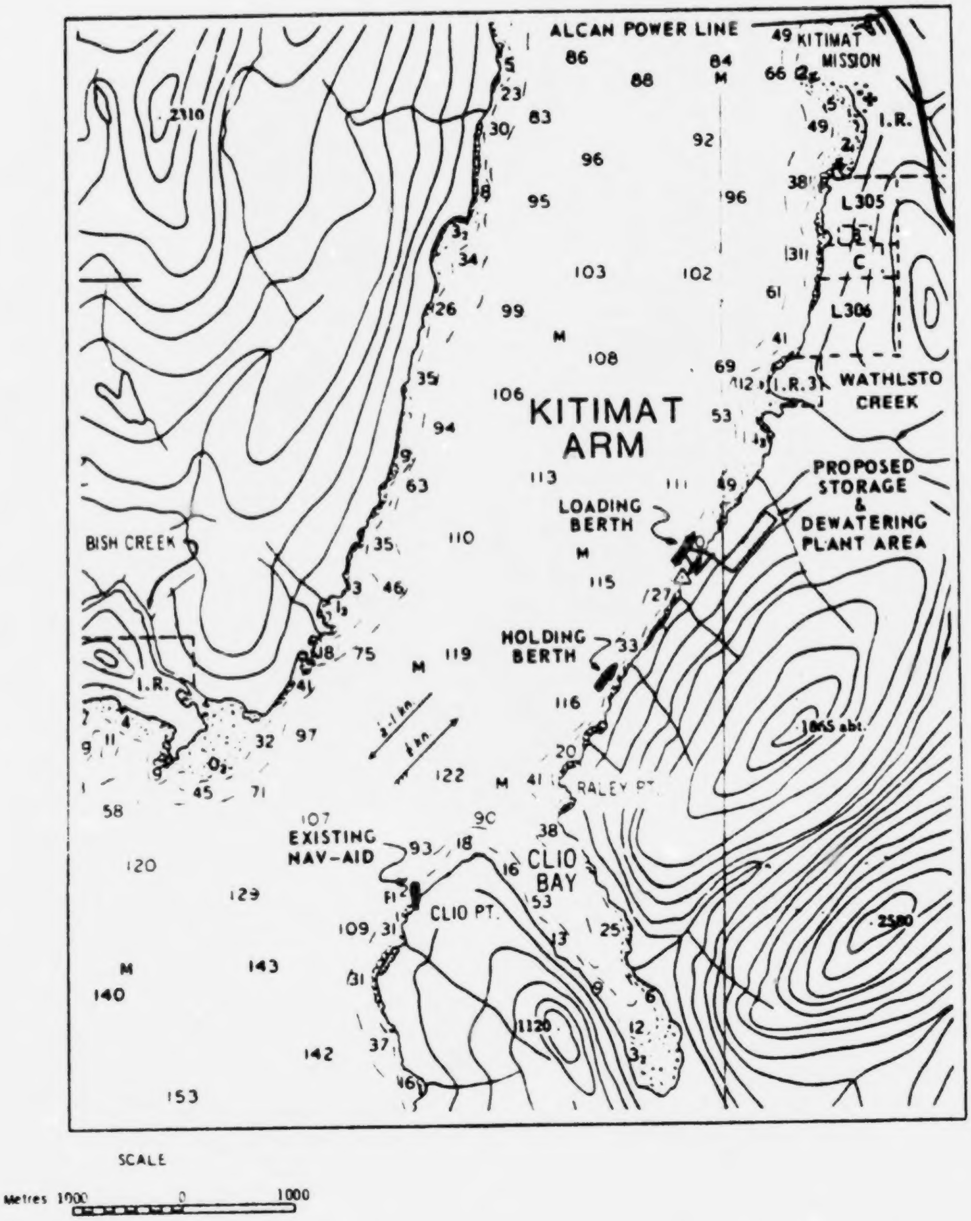

BRITISH COLUMBIA
ALBERTA
USA
TELKWA
TERRACE
KITIMAT
PRINCE GEORGE
HINTON
COALSPUR
MOUNT ROBSON PROVINCIAL PARK
TWEEDSMUIR PROVINCIAL PARK
WILLIAMS LAKE
FRASER RIVER
VANCOUVER
CANADA
U.S.A.

Figure 2


ALCAN POWER LINE
KITIMAT MISSION
I.R.
L305
C
L306
I.R.3
WATHLSTO CREEK
KITIMAT ARM
PROPOSED STORAGE & DEWATERING PLANT AREA
LOADING BERTH
HOLDING BERTH
1865 abt.
RALEY PT.
CLIO BAY
CLIO PT.
EXISTING NAV-AID
BISH CREEK
I.R.
2310
2580
1120
SCALE
Metres 1000 0 1000

WATER DEPTH IN FATHOMS / ELEVATION IN FEET

NOTE: FIGURE BASED ON CHART 3743 CANADIAN HYDROGRAPHIC SERVICE, DEPT OF FISHERIES AND THE ENVIRONMENT, OTTAWA 1977 AND MAP 103H '15, CANADIAN ENERGY MINES AND RESOURCES.

Figure 3 Kitimat Arm port site detail

Water Sourcing

Several different water sources were evaluated to determine which would be most satisfactory for pipeline operations. The study considered waste water from a pulp and paper mill, groundwater, surface water sources, and mine water. Two criteria were used to select an adequate source of water for the pipeline system. The primary criteria was that up to 56,000 litres of water per minute would have to be available. This would supply sufficient water for the expanded throughput case. The secondary criteria was that the water would have to be available continuously. Of the various alternatives the Athabasca River at Hinton, Alberta, appeared to be the most satisfactory water source. The conceptual design would involve the construction of a water distribution system from the Athabasca River to each of the mine site slurry preparation plants and to the central slurry collection plant at Coalspur.

The Slurry Preparation Plants

Each of the five mine sites would have a slurry preparation plant. Each plant would include equipment for slurry preparation, process control, and for receiving, weighing, sampling, crushing, grinding and storing coal. Figure 4 is a flow diagram showing coal receiving, storage, recovery, and slurry preparation. Coal processed through the mine wash plants would be stockpiled, sampled, weighed, and stored for subsequent delivery to the slurry preparation plant at the mine site.

Each mine site preparation plant was designed to produce 20 per cent of the annual coal throughout for the entire system. In the base case, each slurry preparation plant would be required to process 2 million tonnes of coal per year. In the expanded case, each plant would be required to process 3.6 million tonnes of coal per year.

Each process line would utilize a two stage cage mill system for crushing and grinding the coal. The resulting coal would be slurried if it met a specification calling for less than one per cent on 20 mesh and 21 per cent finer than 325 mesh. This coal would be mixed in mechanical agitators to achieve a 53 per cent by weight solids slurry. This concentration would be used in the feeder pipelines that would deliver the slurry to the central coal preparation facility at Coalspur.

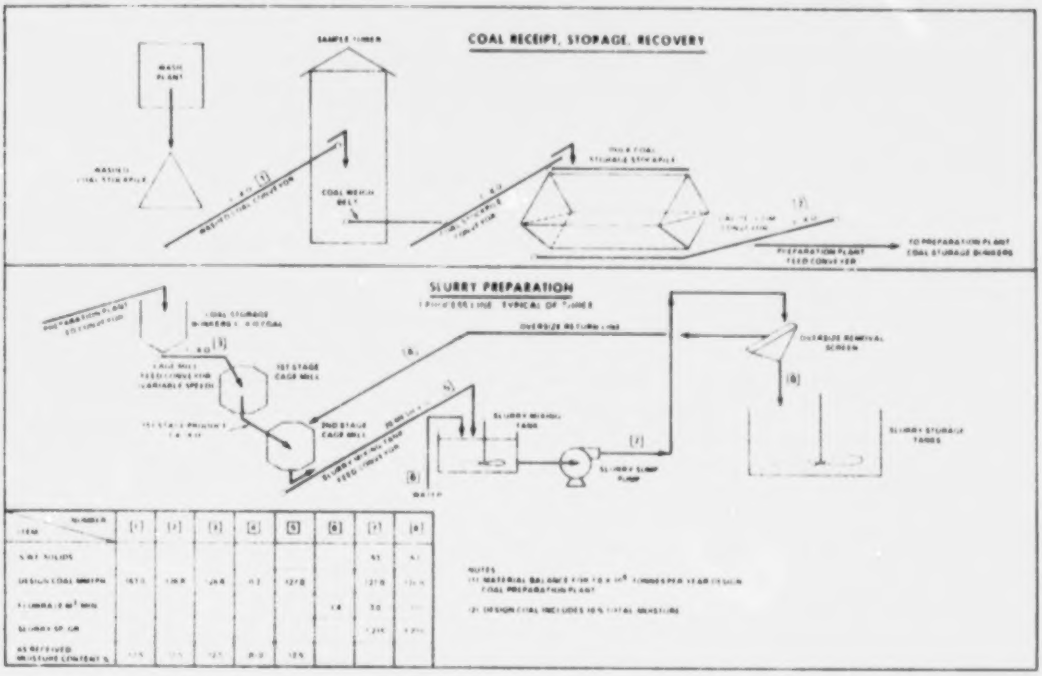


Figure 4 Flow diagram & material balance

The Pipeline System

Slurried coal from each of the five mine sites would be transported to the central slurry collection facility at Coalspur in 254 millimetre diameter feeder pipelines. The slurry would be delivered to mechanically agitated storage tanks which would maintain the concentration at 53 per cent by weight solids. The tanks would provide the feed for the main pipeline, which would use slurry diluted to 51 per cent by weight solids.

The main pipeline pump station would contain two trains of six centrifugal pumps arranged in series to achieve the desired discharge head and flow rate. Along the main pipeline various pumping stations would be built at predetermined locations. The base case would require seven pumping stations at various intervals along the pipeline.

In the base case, a 610 millimetre diameter pipeline of API SLX-60 grade steel with an average side wall thickness of 10.6 millimetres would be used to transport a 51 per cent by weight solids slurry. In the expanded case, an 812 millimetre diameter pipeline of API SLX-60 grade steel, with a maximum wall thickness of 14.0 millimetres, would be used to transport the same concentration slurry. Due to the severity of weather conditions along the route, all pipelines would be buried below the frost ground penetration level, which ranges from 1.4 to 1.9 metres. The pipeline would also be protected against internal and external corrosion.

The Marine Terminal

The proposed location of the marine terminal would be Wathlsto Creek, some 11 kilometres south of Kitimat. A sketch of the candidate port site is shown in Figure 3. Approximately 12 to 29 hectares would be required for the port site based on process area configurations for the storage pond area, the dewatering area, the wastewater treatment area, the product storage area, and the vessel loading area. Sizing of the terminal was based on the random arrivals of vessels, assuming a berth would be occupied by a vessel 40 per cent of the time.

During the course of the study three marine terminal layouts were examined. The first layout was a gravity settling configuration where coal received from the main pipeline would settle in gravity ponds. The coal would then be loaded onto ocean transport carriers at 55 per cent by weight solids. The second layout included coal receiving from the pipeline and mechanical dewatering, with loading of a 60 per cent by weight solids slurry. The third layout included dewatering the slurry to a dry bulk state. Slurry received from the main pipeline would be dewatered as much as possible, so that it would be suitable for dry bulk handling. This dry bulk material, estimated to be between 80 and 90 per cent by weight solids, would be loaded on board ship with conventional conveyor equipment. Figure 5 is a schematic flow diagram of this processing configuration.

The head works of the terminal would be designed to receive the 51 per cent by weight solids feed from the main pipeline. The feed material would report to 100,000 tonne capacity slurry ponds. The number of ponds would vary between the base and expanded cases, but in each case, pond storage for a minimum of 10 days of pipeline operation would be available. From these storage ponds high pressure water re-slurrying equipment would be used to transport the slurry to the dewatering facilities. The dewatering facilities would utilize thickeners, screen bowl centrifuges, solid bowl centrifuges and thermal dryers to dewater the coal prior to ocean going carrier loading. Sufficient coal storage capacity would be available to load two 250,000 D.W.T. carriers. Sophisticated wastewater

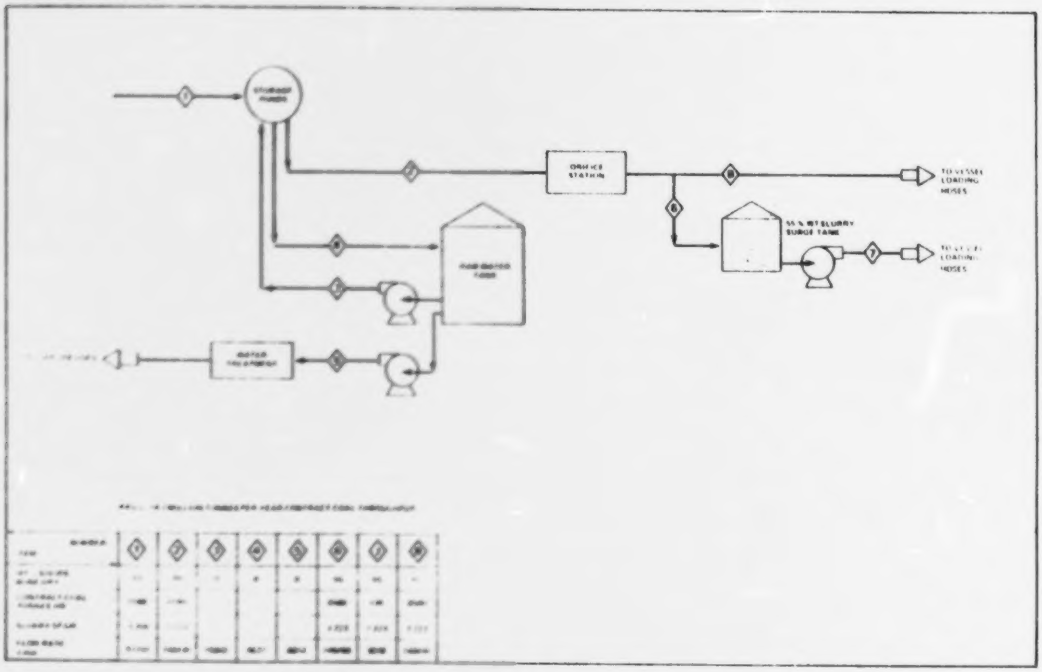

55% wt SLURRY TERMINAL
EXPANDED CASE

Figure 5 Process flow scheme

treatment processes including reverse osmosis and brine concentration processes would be utilized to ensure the aquatic habitat would be protected from any potential adverse impacts form the dewatering operation. Table 2 summarizes the terminal storage, handling and shiploading parameters.

Cost Estimates

The cost estimates in the study were based primarily on telephone quotes from Canadian equipment suppliers. Operating and capital cost estimates are summarized in Table 3. The capital costs include direct field costs, indirect field costs, engineering procurement and management costs, and a contingency. The annual operating expenses include all costs associated with the operation and maintenance of the pipeline system. All costs are in second quarter 1981 Canadian dollars.

Schedule

Figure 6 depicts the anticipated overall project schedule. From the start of preliminary design it is expected that 8 years would elapse prior to the

TABLE 2
TERMINAL STORAGE, HANDLING AND CARRIER LOADING PARAMETERS

	55% Slurry Terminal		60% Slurry Terminal		Dry Bulk Terminal	
	Base Case	Expanded Case	Base Case	Expanded Case	Base Case	Expanded Case
Average Annual Pipeline Delivery Rate, (Tonnes/Hr.) (1)	1,164	2,078	1,164	2,078	1,164	2,078
Maxium Pipeline Delivery Rate, (Tonnes/Hr.) (1)	1,228	2,188	1,228	2,188	1,228	2,188
Cargo Preparation Rate, (Tonnes/Hr) (1)	1,164	2,078	3,309	3,309	1,228	2,188
Carrier Loading Rate, (Tonnes/Hr) (1)	3,309	6,580	3,309	6,580	3,188	6,073
Cargo Capacity of 250,000 DWT Carrier (Tonnes) (1)	148,000	148,000	161,000	161,000	215,000	215,000
Liftings per Annum, (250,000 DWT Carrier)	68.9	123.0	63.4	113.8	47.4	84.7
Mean Interarrival Time for 250,000 DWT Carriers, (Hr)	127.1	71.2	138.2	77.0	184.8	103.4
Mean Loading Time For 250,000 DWT Carriers, (Hr)	44.8	22.5	48.7	24.5	67.9	35.4
Mean Service Time For 250,000 DWT Carriers, (Hr)	50.8	28.5	54.7	30.5	73.9	41.4
Berth Occupancy Ratio Service Time/Interarrival Time	0.4	0.4	0.4	0.4	0.4	0.4
Slurry Storage, (Tonnes) (1)	480,000	720,000	500,000	600,000	300,000	525,000
Prepared Cargo Storage, (Tonnes) (1)	0	0	0	140,000	275,000	250,000

Note: (1) All Tonnes are Contract Tonnes.

commissioning and startup of the pipeline. If the decision was made in 1982 to construct the pipeline, it could probably begin transporting coal in 1990.

TABLE 3
ESTIMATED CAPITAL AND OPERATING COSTS FOR THE COAL SLURRY PIPELINE SYSTEM
(in millions of 1981 Canadian dollars)

	Base Case	Expanded Case
Pipeline Capital Cost		
55% Wt. Slurry Marine Terminal	1,676	2,225
60% Wt. Slurry Marine Terminal	1,763	2,353
80% Wt. Dry Bulk Marine Terminal	1,848	2,493
Annual Pipeline Operating Cost		
55% Wt. Slurry Marine Terminal	38.1	54.7
60% Wt. Slurry Marine Terminal	53.0	74.4
80% Wt. Dry Bulk Marine Terminal	60.8	91.4

Source: Fluor Canada Ltd., Coal Slurry Pipeline Feasibility Study 1981, November 1981

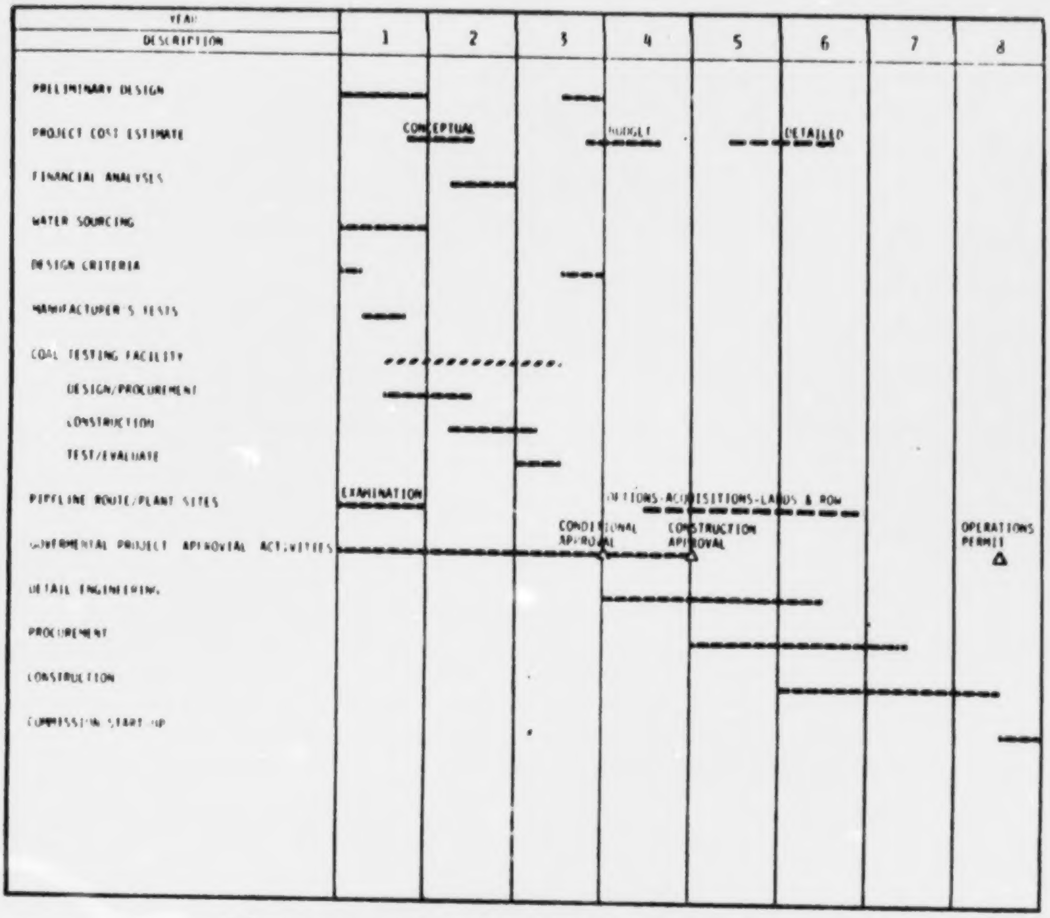


Figure 6 Overall project schedule

Economic Feasibility

The study concluded it would be technically feasible to transport thermal coal from Alberta to British Columbia by slurry pipeline utilizing state-of-the-art technology for slurry transport systems. However, as shown in Table 3, the pipeline system would be expensive. To be economically feasible, the slurry pipeline system would have to be competitive with a unit train operation. The remainder of this paper summarizes an attempt by the government of Alberta to determine whether a coal slurry pipeline could be a cost competitive mode for transporting Alberta thermal coal to the west coast of British Columbia for export.

The objective of the analysis was to evaluate the pipeline as a competitive mode of transport. Therefore, it was necessary to focus on the pipeline alone and not on the entire coal production and marketing system. Coal suppliers, coal quality, ocean transport, and coal marketing were not considered in the analysis. These topics, as will be seen later, are critical to the overall economic feasibility of constructing and financing a slurry pipeline.

For a pipeline to be competitive it must be able to offer rates and service to a coal shipper which are as good as or better than the railway. However, at the minimum, investors in a pipeline would expect revenues which, over the life of the project, would cover operating costs, taxes, repayment of the invested capital, and a return on the amount invested.[1] This revenue would have to be generated in an environment where the rates charged would be competitive with railway rates. Railway rates would also have to generate sufficient funds over the life of the project to cover operating costs, taxes, repayment of principal and a required return to investors.

It is interesting to note that in the absence of competition, both modes could set rates higher than the minimums described above. However, it is the minimum rate levels which provide a meaningful comparison between the modes. The transport mode able to offer the lowest rate and still meet the minimum cash flow requirements was considered to have the competitive advantage.

In order to develop these minimum rates the following methodology was followed:

(1) Definition of a rail system as comparable as possible to the pipeline system.

(2) Calculation of the capital costs and the annual cash operating costs for both modes.

(3) Development of an inflation forecast.

(4) Development of financing scenarios for each mode.

(5) Calculation of the minimum rate levels.

(6) Identification of economically sensitive areas.

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[1] Including interest to debt holders and dividends and/or gains to equity holders.

The remainder of this paper summarizes the results of each of these steps.

The Pipeline System

For the purposes of this analysis, four pipeline options were examined: (1) a pipeline shipping 10.2 million tonnes of coal per year with no dewatering at the port site (a 55 per cent by weight slurry marine terminal), (2) a pipeline shipping 10.2 million tonnes of coal per year with a 90 per cent by weight dry bulk marine terminal (coal slurry dewatered to 10 per cent moisture), (3) a pipeline shipping 18.2 million tonnes of coal per year with no dewatering at the port site, and (4) a pipeline shipping 18.2 million tonnes of coal per year with a 90 per cent by weight dry bulk marine terminal.

Capital and operating costs for each of these options are shown in Figures 7 and 8. As mentioned previously, all these costs were estimated in the *Coal Slurry Pipeline Feasibility Study 1981* which was commissioned by the Government of Alberta.

The Rail System

Since the objective of this analysis was to determine which mode was more cost competitive, every effort was made to keep the rail system as comparable as possible to the pipeline system. As shown in Figure 9, the rail and pipeline systems start to diverge at the wash plant. As a result, the following cost comparisons start at the wash plant and go all the way to the port terminal.

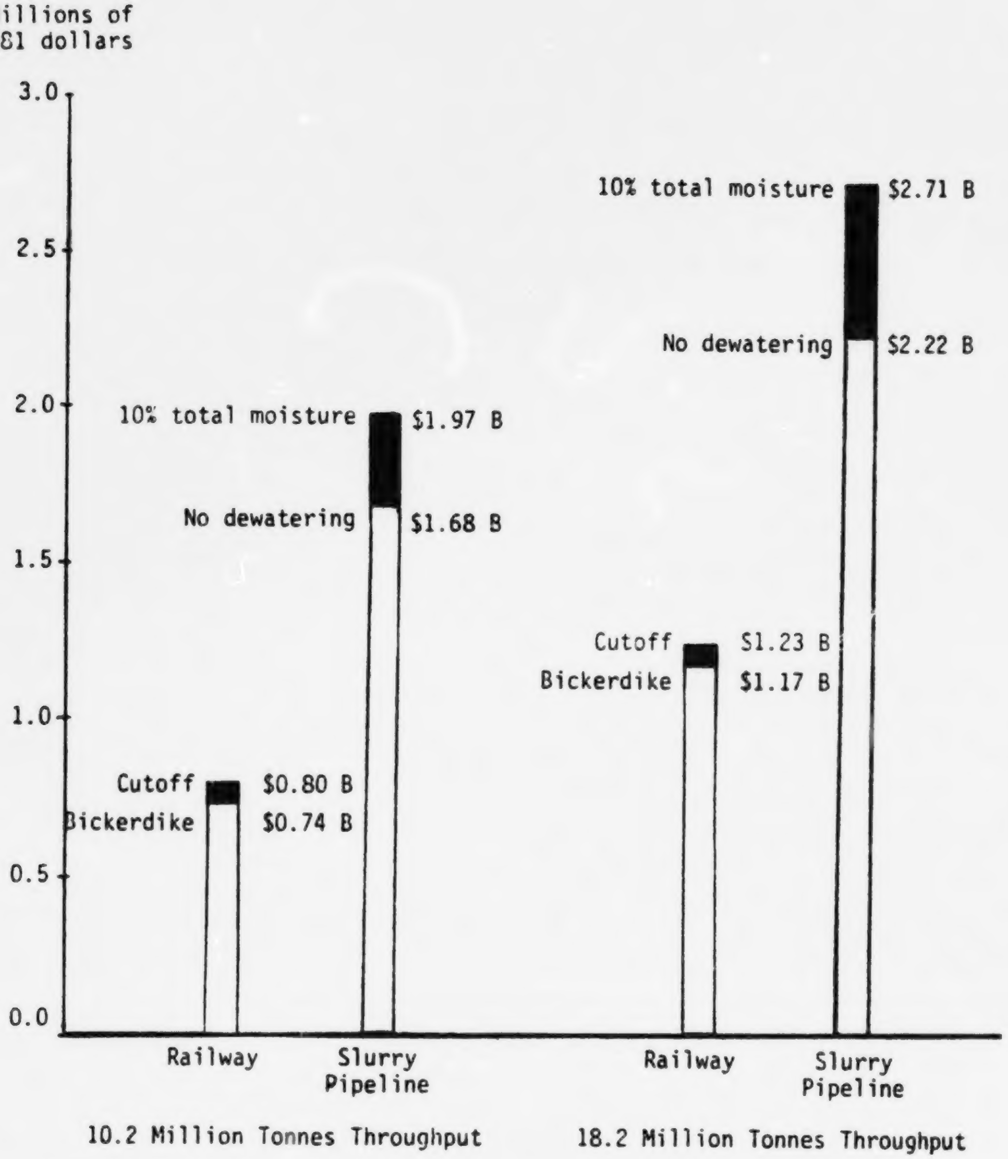


Figure 7 Railway and slurry pipeline capital costs

In defining the rail system, the objective was to develop as efficient a system as possible. A 108 car unit train was used to move the coal 1,390 kilometres from five mine sites in the Coalspur area to the port of Prince Rupert. Prince Rupert was chosen over Kitimat because of the infrastructure being put in place there to serve the northeastern British Columbia coal developments and in order to avoid upgrading the rail line from Terrace to Kitimat.

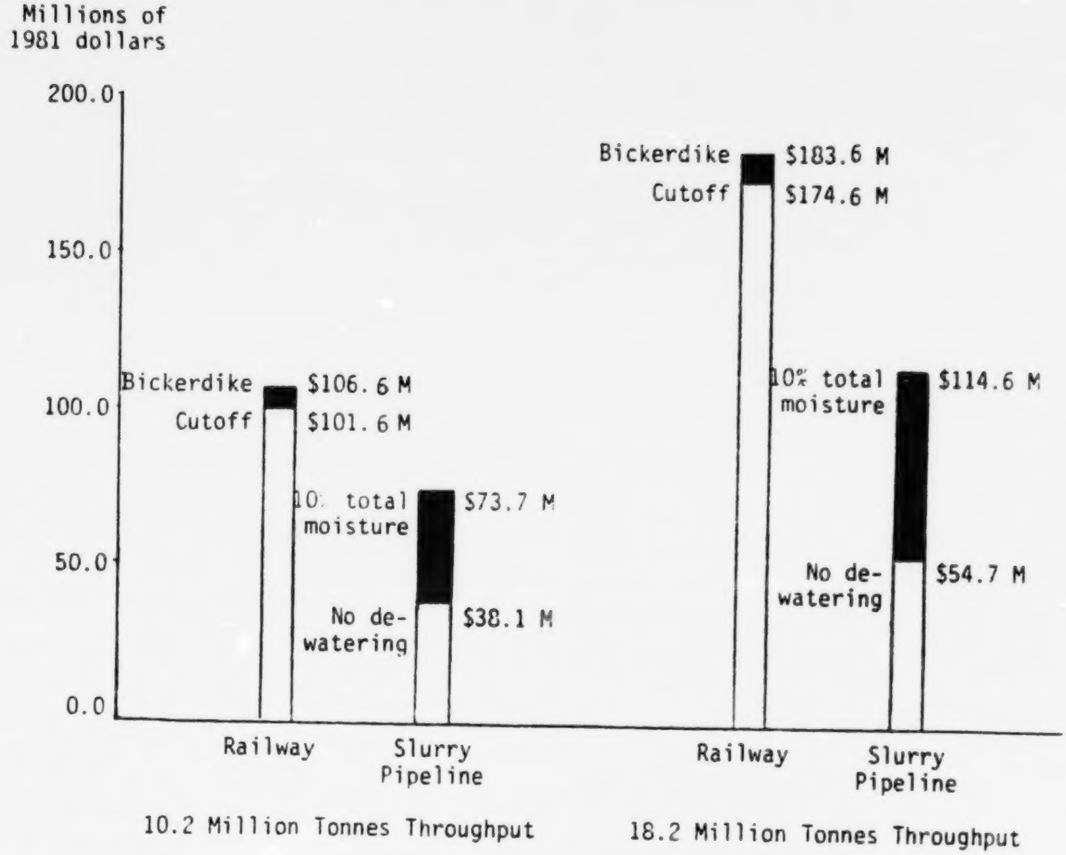


Figure 8 Railway and slurry pipeline operating costs

The grades and curves on the rail line serving the Coalspur area mean the train must be broken into the pieces at Bickerdike. To avoid this problem, the possibility of constructing a new spur line from Robb to Obed was also evaluated. This gave us two rail options: the route over existing track via Bickerdike, and the cutoff route over new track to Obed.

While the pipeline would probably be operated by a single entity, a comparable rail system would be operated by three separate entities: the coal company, the railway, and the port terminal operator. The coal company would operate the unit train, and the port terminal company would operate the marine terminal. The costs of each of these three components were developed separately and then summed to calculate the total cost for each rail option.

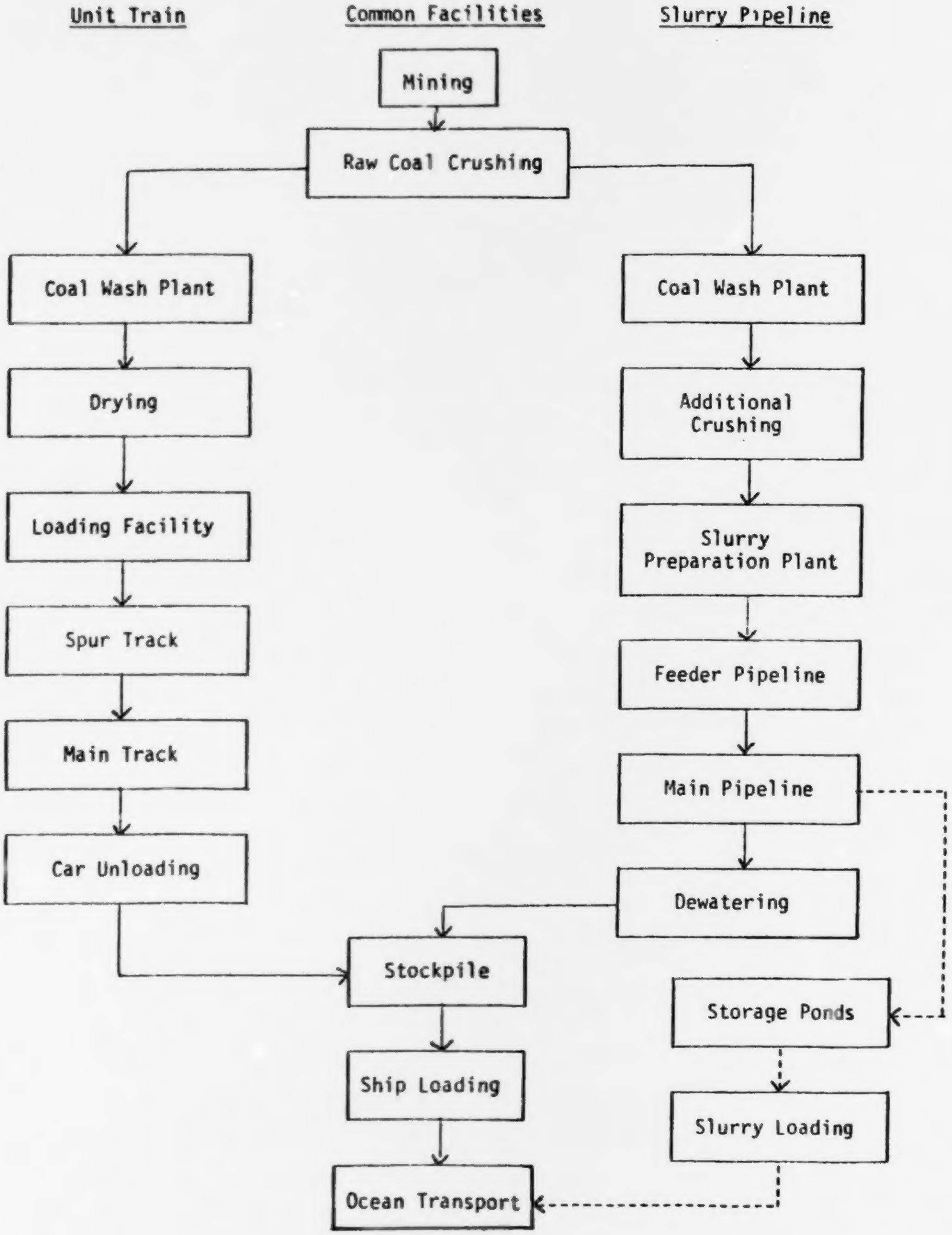

Unit Train
Common Facilities
Slurry Pipeline
Mining
Raw Coal Crushing
Coal Wash Plant
Drying
Loading Facility
Spur Track
Main Track
Car Unloading
Coal Wash Plant
Additional Crushing
Slurry Preparation Plant
Feeder Pipeline
Main Pipeline
Dewatering
Stockpile
Ship Loading
Ocean Transport
Storage Ponds
Slurry Loading

Figure 9 Comparison of unit train and slurry pipeline systems

Rail capital and operating costs were developed through a series of sub-studies. The rail capital cost estimates shown in Figure 7 are the incremental capital costs required to handle new coal traffic. Rail capital cost estimates include the new train sets and the infrastructure required over and above what the railways plan to have in place by 1990.

Inflation

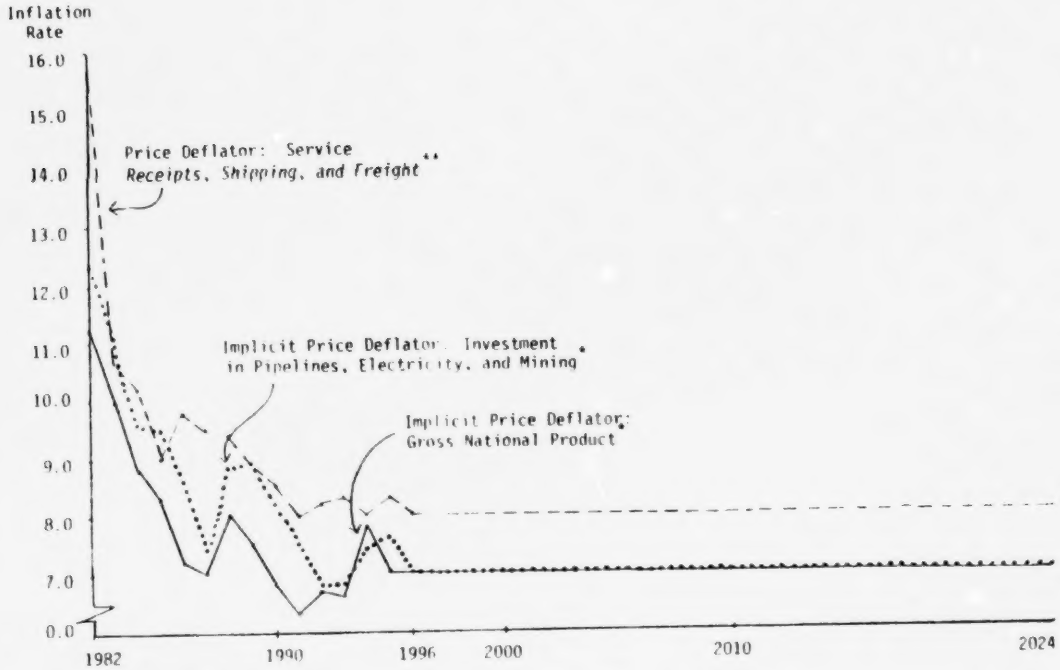
Since they have different proportions of capital and operating costs, inflation would affect the pipeline and railway alternatives differently. Thus, all input costs were converted to current dollars using a series of sector price deflators published by Data Resources Incorporated. All capital costs were inflated using the Investment in Pipelines, Electricity and Mining deflator and all operating costs were inflated using the Service Receipts, Shipping and Freight deflator. These indices are shown in Figure 11. The Gross National Product price delfator is included in this figure for comparison purposes only. Note that the indices used for capital and operating costs stabilize at an annual rate of 7.0 per cent and 8.0 per cent respectively in 1966. These same indices were used to inflate rail and pipeline capital and operating costs from 1990 through to the end of the project's life in 2024.

Financing

After careful consideration it was decided that the pipeline, with its discrete cash flows and opportunities for risk sharing with buyers and sellers, could be financed on a project basis. The railway, on the other hand, would have to use traditional corporate financing. Canadian National Railways is required to maintain at least a 40/60 debt/equity ratio. The financing assumptions utilized in the analysis are summarized in Table 4. In each case, the tax liabilities net of capital cost allowances and investment tax credits were estimated.

Minimum Rate Levels

The rail and pipeline cost estimates were used to generate cash flows for each mode over the 35 year life of the project. The next step was to calculate the minimum rate levels required by each mode to cover all costs. Since 1990 was the year both modes were assumed to begin operating at full design capacity, it was used as the base year for calculating the minimum rate levels. After 1990, both rail and slurry pipeline rates were assumed to grow at the same rate of inflation for the 35 year life of the project. By



Source: Data Resources Inc.

Footnotes

*January 31, 1982 Long term forcast

**Canadian Review: Spring, 1982.

Figure 11 Forecast inflation rates

TABLE 4
FINANCING ASSUMPTIONS

	Debt / Equity Ratio	Cost of Debt (after tax)	Cost of Equity (after tax)	Debt Repayment Period
Slurry Pipeline	75 / 25	17%	20%	20 years
Rail Loading Facility	70 / 30	15%	18%	20 years
Canadian National Railways	40 / 60	15%	18%	20 years
Marine Terminal	70 / 30	15%	18%	20 years

making this assumption, we were implicitly assuming that real rate levels would not change over the life of the project. If this were the case, the mode with the lowest rate in 1990 would be the mode with the lowest rate during the entire life of the project. Therefore the most cost competitive mode in 1990 was also judged to be the most cost competitive mode over the life of the project.

The 1990 rate levels calculated for each mode and option are shown in Figure 12. The graphs in this figure illustrate the results of the minimum rate level analysis. They show that:

(1) There are significant economies of scale with the slurry pipeline.
(2) As the amount of dewatering increases, the slurry pipeline becomes less competitive.
(3) Construction of the rail cutoff appears to become economic at a throughput of about 11 million tonnes per year.

Economically Sensitive Areas

Numerous assumptions and estimates were used throughout the analysis. The most important assumptions and estimates were modified to determine if this would significantly affect the cost competitiveness of each mode. Several economically sensitive areas were identified for the railway and for the slurry pipeline. In these areas, significant changes in minimum tariff levels resulted when important assumptions or estimates were modified. The most important sensitivities are summarized below:

(1) Taken in isolation, a drop in the interest rate was more beneficial to the pipeline than it was to the railway.
(2) The railway was more sensitive than the pipeline to changes in capital and operating cost estimates.
(3) The greater flexibility in the rail option made it much less vulnerable than the slurry pipeline to a loss of traffic.
(4) When the pipeline was financed in a similar fashion to the railway, the pipeline rate of $48 per tonne rate rose to $80 per tonne. The pipeline was extremely sensitive to the method of financing.
(5) When the pipeline rates were calculated under the conventional rate base of return method commonly used by Canadian regulators, the pipeline rate of $48 per tonne rate rose to $86 per tonne. The

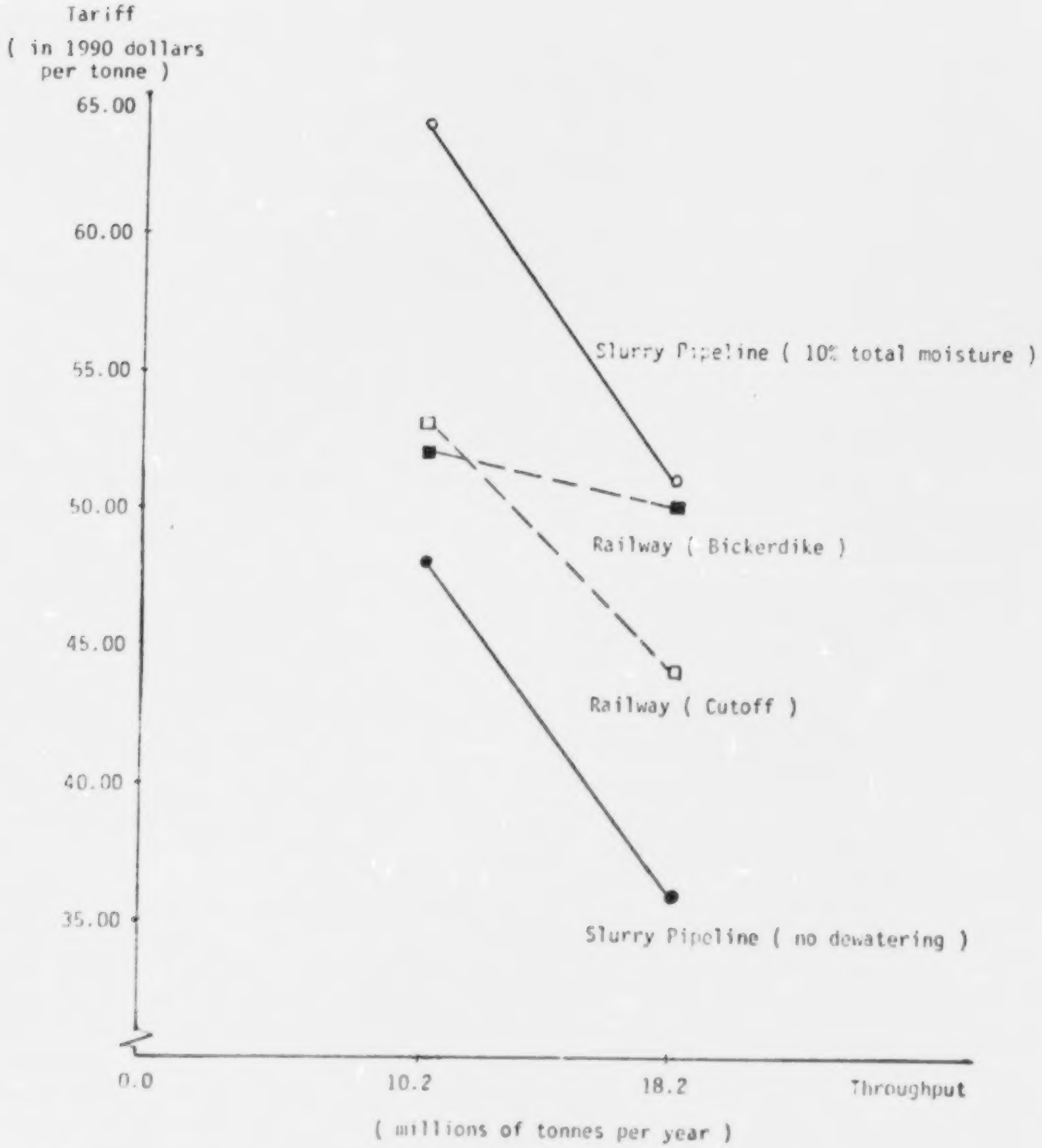


Figure 12 Railway and slurry pipeline tariffs in 1990

effect of rate base regulation on pipeline tariffs is illustrated in Figure 13.

(6) Rail rate estimates were developed on a number of other bases summarized in Figure 14. When compared to the results obtained from this analysis, they appeared to be consistent.

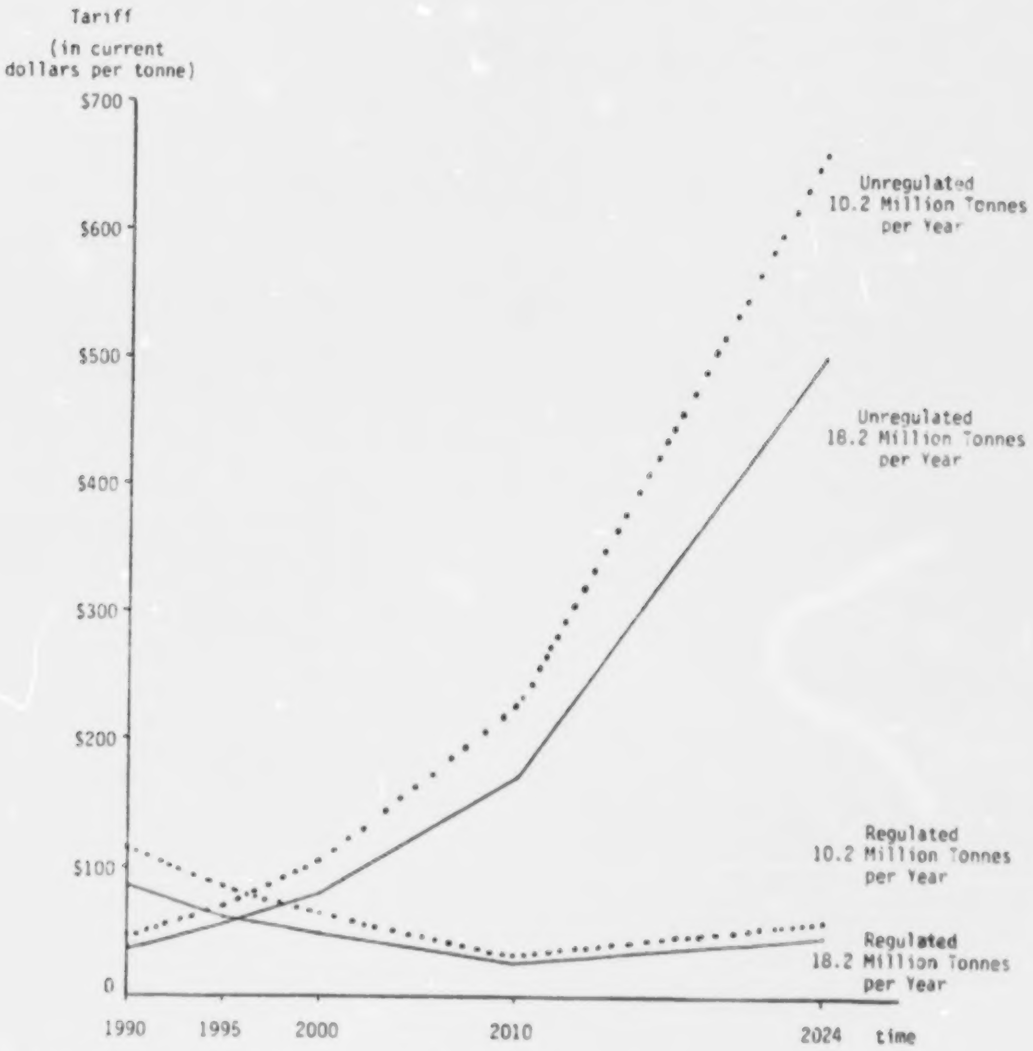
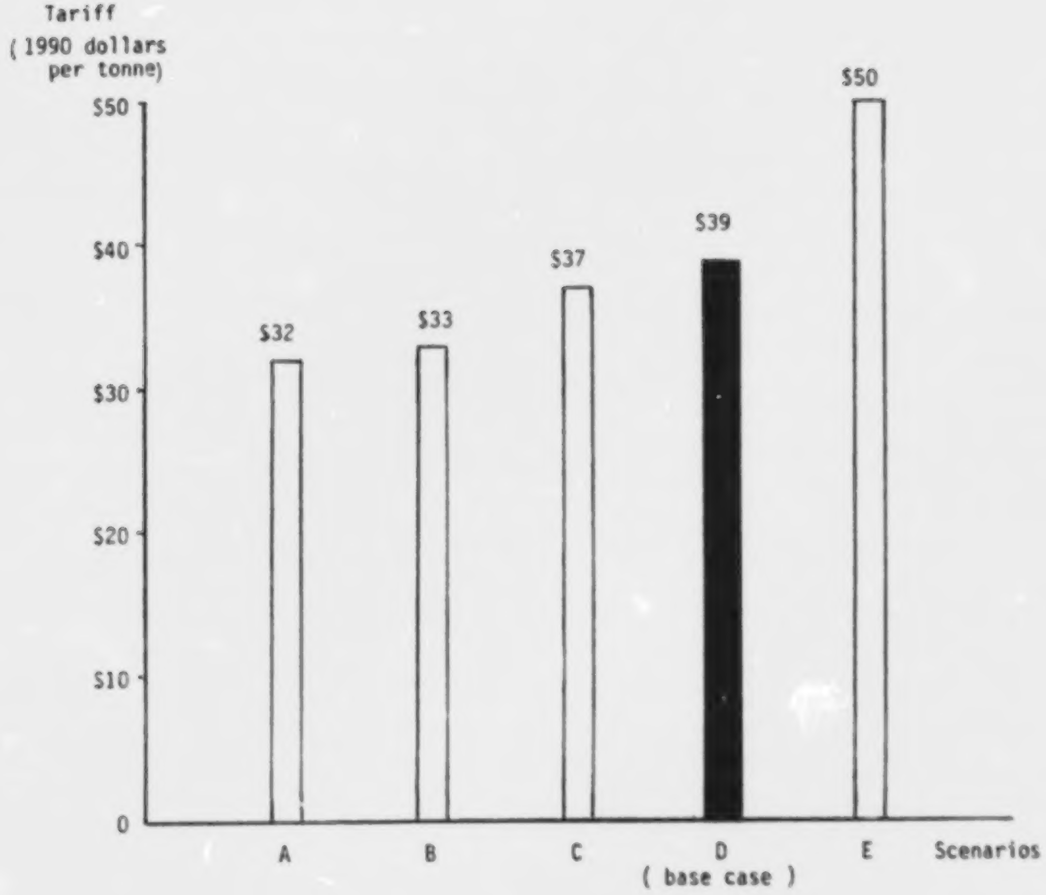


Figure 13 Impact of regulation on slurry pipeline tariffs

Conclusions

The closeness of the minimum rates calculated for the railway and the slurry pipeline and their sensitivity to key assumptions made it difficult to reach definitive conclusions concerning the cost competitiveness of a coal water slurry pipeline. However, the marketplace's current preference for coal in the dry bulk state does suggest that certain technical improvements could increase the feasibility of constructing the pipeline.



Scenario A: Current railway rates inflated assuming that operating costs will increase at the expected inflation rate, while capital costs remain constant.

Scenario B: Current railway rates inflated by 8 per cent per year.

Scenario C: Current railway rates inflated by expected inflation rates.

Scenario D: Railway rates calculated for 10.2 million tonnes per year (the base case).

Scenario E: Current railway rates inflated by the average rate of increase during the five years previous to 1982 (13.83 per cent).

Figure 14 Forecast railway rates in 1990

Compared to railways, slurry pipelines are a new technology. In the course of the analysis it was possible to identify the following technical improvements which could enhance their competitiveness with unit trains:

(1) Reduction in the amount of dewatering by development of new burning technology or by reduction in the cost of dewatering.
(2) An increase in the concentration of coal by weight to enhance operating efficiency and to possibly reduce dewatering costs.

Aside from these technical improvements, the competitiveness of the slurry pipeline could be further enhanced by the following developments:

(1) Capture of markets for increased volumes of coal.
(2) Reduction in the capital costs of construction.
(3) Lower interest rates.

The foregoing analysis showed that conventional rate base rate of return regulation would drastically decrease the economic feasibility of the slurry pipeline. More importantly, it demonstrated that without project financing the pipeline could not compete with the railway. The key to project financing is the sharing of risk between the participants in the project, including coal producers, pipeline owners, and coal buyers. Risk sharing would require a complex series of negotiations with a vast number of possible outcomes. Therefore, it is recommended that further analysis of the slurry pipeline be done on a system basis (i.e. from mine to burner tip) by entrepreneurs interested in pursuing this new and exciting technology.

Acknowledgements

The authors are grateful for the permission of the Alberta Government to use material from the Coal Slurry Pipeline Feasibility Study 1981 in this paper. They also wish to acknowledge the following individuals and organizations who made valuable contributions to this work: Darryl Howery and Jennifer M. Mazur of Alberta Economic Development, Zisos A. Kastiapis and Robert A. Ogrodnick of Alberta Energy and Natural Resources, Woods Gordon Management Consultants, Simon-Carves of Canada Ltd., DeLeuw Cather Canada Ltd., Pipeline Systems Inc. of Orinda, California, and Fluor Ocean Services Division of Houston, Texas.

Questions on Paper by Rabb and Bassett

Q: Did you assume a reasonable start-up scenario?

A: We assumed one mine would come on-stream every six months. The first mine would start shipping coal in January of 1990. All five mines would be on-stream by January of 1992.

Q: Assuming start-up is possible, would it be necessary to pool products or would batching be possible?

A: This has not been looked at.

A: It should be looked at.

A: The US experience showed batching was possible.

A: There is a big difference between dry and wet coal power generation efficiency. There is a need to look at the impact on end users.

Q: Your estimated 1990 tariffs cover the discounted costs over the life of the coal movement?

A: Yes. The 1990 tariffs cover the net cash flows discounted over the life of the project.

Q: The start-up scenario seems a bit iffy. I also question your assumption about single-price and single-quality coal coming from five different mines. Mixing different quality coals is a significant problem in the market place.

A: You could batch different grades of coal in the pipeline, but Fluor did not study that option.

A: In the United States, we do not work on quality dilution. It seems manageable. Each company could negotiate their own contract.

Q: It makes a difference to coal consumers if they receive coal slurry instead of dry bulk coal, because there is an 8-10 per cent inefficiency in steam generation with slurry. So customers would require about 10 per cent more coal in slurry form to generate the same BTU's.

A: Yes. But there are also some advantages to burning slurry instead of dry coal. For one thing, you can eliminate your crushing costs.

Editor's Note: With the slurry system, crushing costs would be incurred at the mine site, instead of at the power plant.

A: And delivering coal in slurry form may also be cheaper than delivering it in conventional dry bulk form.

A: I think CANMET is currently investigating the burning of slurries in the Maritime provinces. Their research should resolve the thermal efficiency issue.

Q: What pumping pressures was the pipeline designed for?

A: They are specified in Fluor's report.

A: They are the same pressures utilized in the conventional Black Mesa type design.

Q: What about the upgrading required on the existing rail system?

A: We assumed a large rail capital investment would be required to handle the additional coal traffic. About $800 million to ship the additional 10.2 million tonnes of coal, and about $1.3 billion to ship 18.2 million tonnes (in 1981 dollars). The high level of capital investment translates into high rate forecasts. We assumed the railways would not accept this coal traffic unless it would pay for the required capital investments to upgrade the rail line.

Q: Has the adequacy of rail capacity been considered?

A: The rail cost was the incremental cost of carrying this volume of coal.

Q: Why didn't you look at the rail system for moving coal to Vancouver?

A: Because we wanted a rail system comparable to the pipeline, which terminates at Kitimat.

A: It is also questionable whether it would be possible to double track through the Fraser Canyon in order to move this additional coal traffic.

A: We were assuming these tonnages would be over and above what is currently forecast to move. We are talking about very large volumes of coal traffic.

September 27, 1982
AFTERNOON SESSION

Rutherford: Coal in Methanol Slurries

Ron Rutherford, Chieftain Development Co. Ltd., Edmonton, Alberta

West Coast Transmission, Chieftain Development Co. Ltd. and the Alberta government have recently completed a study which evaluates several projects which have been proposed to develop the Province of Alberta's natural resources.

This was not a technical investigation. The economics of each project were evaluated to identify which projects were potentially feasible and worth further study.

Much of our research dealt with the feasibility of coal methanol slurries. We did a literature search, and went to Germany to find out more about the research underway there which had produced some encouraging results. The coal methanol slurry appears to be technically feasible and has the economic advantage of transporting energy - not water.

We also went to Japan to talk to a group of fifteen companies which has done a great deal of work on coal methanol mixtures. We agreed to work together with them, utilizing their technology.

Our study looked at the economic feasibility of a coal methanol slurry pipeline from Hinton, Alberta, to Kitimat and to Vancouver in British Columbia. However, most of our analysis focused on Kitimat. The methanol would be produced from natural gas in the Hinton area. The Japanese did most of the work on ship design, receiving facilities in Japan, and utilization of the coal methanol slurry in Japan. The Japanese were very protective about their technology, and required us to sign secrecy agreements.

We estimated capital and operating costs for the pipeline system, based on Japanese design applied to Canada. We costed two pipeline systems: 6 million tonnes and 18 million tonnes of coal per year. The slurry was 50 per cent coal and 50 per cent methanol. We hired a number of consultants to provide us with some detailed cost estimates.

The next question was: Is it marketable? If the first phase looked reasonable, we wanted to identify areas for further study and to look at where costs could possibly be reduced.

Originally, we thought the coal methanol slurry could be burned directly as a fuel. We wanted to interest the Japanese Ministry of International Trade and Industry (MITI) and the Japanese power generation companies to use it as a fuel. Since this was not economically attractive, we then looked at separating the coal and methanol. This split the project in two. Markets had to be found for the coal and also for the methanol. This option was not feasible either because there is currently an over-supply of methanol on world markets. We would need a market for very large quantities of methanol. After evaluating the current world-wide market for methanol, we also prepared a demand forecast for methanol use in the transportation industry.

It was also discouraging to find the cost of manufacturing the coal methanol slurry was higher than we had expected. The slurry was a very fine grind, so the coal would not settle out in the pipeline. The slurry could be transported in much the same way as crude oil. Perhaps this is the wrong kind of slurry. Some other type, such as a coarse slurry, may be more economically attractive. However, this would require another study.

Our research included all the elements of the coal chain including the methanol plant, slurry production, and the pipeline. When we finished, we had looked at the feasibility of eight projects. The cost estimates have not been made public as yet.

Part of the study looked at methanol produced from coal instead of from natural gas. We found it would be considerably more expensive to produce methanol from coal.

Fluor Canada Ltd.'s Coal Slurry Pipeline Feasibility Study 1981 was a great source of information, particularly on the pipeline route and on the marine terminal. It was utilized extensively.

We didn't want the coal methanol slurry pipeline to fail due to environmental constraints, so we also investigated what permits and other environmental requirements would be required.

Questions on paper by Rutherford

Q: Can you elaborate on your assessment of world markets for methanol?

A: There were many different opinions in Europe concerning the future use of methanol in the transportation industry. The most likely use for methanol is as a gasoline additive. In one study, vehicles were operated on 100 per cent methanol, on 15 per cent methanol and 85 per cent gas, and on 3 per cent methanol and 97 per cent gas. 100 per cent conversion to methanol would be difficult because there is no established distribution network. However, it could be achieved with fleets of vehicles. The 15 per cent conversion test was cancelled because 30 per cent of the vehicles experienced mechanical problems burning this fuel mixture. This leaves the 3 per cent conversion as probably the most likely.

We looked at methanol markets in Germany, Holland, France, Britain, Italy, Japan and the United States. The growth of methanol consumption was forecast based on its use as a 3 per cent additive to gasoline. However, with respect to the pipeline, 3 million tonnes of methanol comprise a very large volume compared to current world production. For the project to be feasible, we need a larger market for methanol.

Q: Isn't there an advantage to put the pipeline development last, after the methanol market is established, to ensure the economic feasibility of the concept?

A: The only real hope would be to tie the pipeline to Japanese industrial energy programming. The project would be too risky otherwise.

Q: Is there any intent to examine unanswered questions remaining from the study?

A: Unless the sponsors saw the likelihood of a project at the end of the road they would not likely be interested in continuing the research.

Q: Why did you study coal methanol slurry? It would seem more logical to transport the methanol to the coast in the underutilized Trans Mountain pipeline.

A: The sponsors of our study had coal and natural gas to ship - not methanol.

Q: What areas did you identify for further study? Who will study them?

A: The results of our study were inconclusive. It will be difficult to generate additional funds for further research without an attractive project to generate the interest.

The areas which need to be looked at are:

(1) the advantages of fine versus coarse coal slurry;

(2) the opportunities for reducing the cost of manufacturing coal methanol slurry;

(3) the economics of coal water versus coal methanol slurry. We started looking at coal water slurry but switched to coal methanol slurry because our sponsors wanted to sell natural gas.

Q: Did you look at recycling the methanol through the system?

A: Yes. But it did not appear to be economically attractive because the pipeline was very long - between 700 and 1000 miles. Besides, this was a joint study, and the Japanese had their own ideas about what should be studied. However, we did look at bringing the methanol back to Canada from Japan on ships.

Q: Why not separate the coal and methanol at the marine terminal in Canada?

A: There is enough methanol on the west coast already.

Gödde: Assessment of Methanol as a Carrier Liquid for Coal Transport Through Pipelines

Assessment of Methanol as a Carrier Liquid for Coal Transport Through Pipelines

Ewald Gödde, Pipeline Engineering GmbH, Essen, Germany

Dedicated to Professor Dr.-Ing. E. Bahke on his 65th birthday

Summary

The use of pipelines for the transportation of coal in slurry form has great advantages over more conventional means of transport. At present water is usually used as a carrying medium but this has some disadvantages. The author reviews the possible use of methanol as an alternative and discusses at length the pertinent economic and technological factors involved.

1. Introduction

The continually rising price of oil and the realization that oil reserves are limited have led to a resurgence of coal in the industrialized nations. For coal to play an important role in the future, new processes must be developed to adapt this source of energy to the needs of domestic and industrial consumers and to take into account environmental considerations. In addition, large quantities of coal, or energy produced from coal, must be transported at economical conditions from the coal fields over considerable distances to the main centres of consumption. The present capacity of conventional overland and marine transport facilities (railways, ships and ports of transshipment) would not be sufficient to meet the increasing demands for coal transportation. Considerable efforts are therefore being made throughout the world to develop means of converting coal into consumer-oriented gaseous or liquid fuels which can be transported economically through pipelines, much in the same way as gas or oil. The advantages of pipeline technology have already been realized in transporting slurries of fine ground coal and water on a commercial scale. The hydraulic transport of coal has proved to be as economical as pipeline transportation of other raw materials such as iron ore, phosphates and limestone. Nevertheless, coal-water pipelines have some disadvantages. Firstly, water has no fuel value and is therefore mere ballast; secondly, the pipeline must be buried as a protection against frost, and in addition, the coal must be dewatered after transportation, a process which involves considerable cost. In an article on "Alternative Carrying Media and Agglomeration Processes for Transportation of Coal"[1], the use of oil, methanol, ethanol, LNG and CO_2 as alternatives to water for the pipeline transportation of coal have already been discussed. None of these alternatives has yet been used on a commercial scale, although it is generally recognized that methanol (CH_3OH) is most likely to be used.

One of the major advantages of methanol is that it can be produced from the coal itself via the processes of gasification and methanol synthesis. Furthermore, methanol is not mere ballast like water, but a source of energy, which is clean and can be easily transported.

After transportation, coal-methanol slurry can be used directly to fire power stations. There are various other possibilities; after separation, the methanol can be used to fire power stations during periods of high demand or as a chemical feedstock. Finally, the methanol can be returned to the head station of the pipeline and reused for transportation. As methanol has a low freezing point, the pipeline need not be buried.

Studies have therefore been undertaken concerning the suitability of methanol as a carrying medium for the pipeline transportation of coal.

2. Chemical and Physical Properties of Methanol; Safety Aspects

Methanol is a colourless flammable liquid with a mildly alcoholic, slightly pungent characteristic odour. The methanol molecule (CH_3OH) consists of an OH group and a methyl radical; its chemical properties are therefore more similar to those of water than to those of hydrocarbons. In contrast to benzine, the methanol molecule has only one carbon atom (C) and therefore does not have a C-C-carbon bond. In addition, methanol has one oxygen atom (O) and therefore belongs to the group of oxygeneous fuels.

Table 1 shows the main properties of methanol.

At 60°C, methanol has the same kinematic viscosity as water (0.45 cSt); between 60°C and 0°C the kinematic viscosity of water is greater than that of methanol. The kinematic viscosity of methanol increases progressively from its boiling point (65°C) to its freezing point (-98°C).

Methanol has a higher heating value of 22.46 MJ/kg and a lower heating value of 19.67 MJ/kg.

TABLE 1
PROPERTIES OF METHANOL (CH_3OH)

Boiling Point	65°C	Flash Point	11°C
Melting point:	-98°C	Flammability limits (% by volume)	
		Upper	26.5%
		Lower	5.5%
Density at 0°C:	0.81 g/cm^3	Self-Ignition temperature:	450°C

Appearance:
Colourless liquid; odour similar to that of diluted shellac

Miscibility:
Completely miscible with water in all proportions

Explosion Hazards:
When mixed with air or water

Health Hazards:
Both as liquid and vapour, has toxic effects on central nervous system, optical nerves, kidneys, liver, heart and other organs.

Symptoms:
Intoxication, dizziness, headaches, nausea, fainting, impairment of vision, unconsciousness, respiratory arrest.

Threshold for Olfactory perception:
5 ppm

Because of its toxicity and the explosion hazards it presents, methanol must be handled with great care; however, expert opinion is that a coal-methanol slurry pipeline would be no more hazardous than oil or product pipelines.

3. The Preparation and Use of Methanol; Cost Considerations

The preparation of methanol always involves the hydration of carbon monoxide and carbon dioxide according to the following equations:

$$CO + 2H_2 - - CH_3OH$$
$$CO_2 + 3H_2 - - CH_3OH + H_2O$$

To date, methanol has mainly been produced from natural gas, although heavy fuel oil has also been used. Fig. 1 shows the feedstocks and methods used to produce methanol and its various applications and end products². In view of the potential applications and the importance of methanol as a source of energy and as a carrying medium for the pipeline transportation of coal, coal will probably increasingly be used as a feedstock for methanol synthesis in the future.

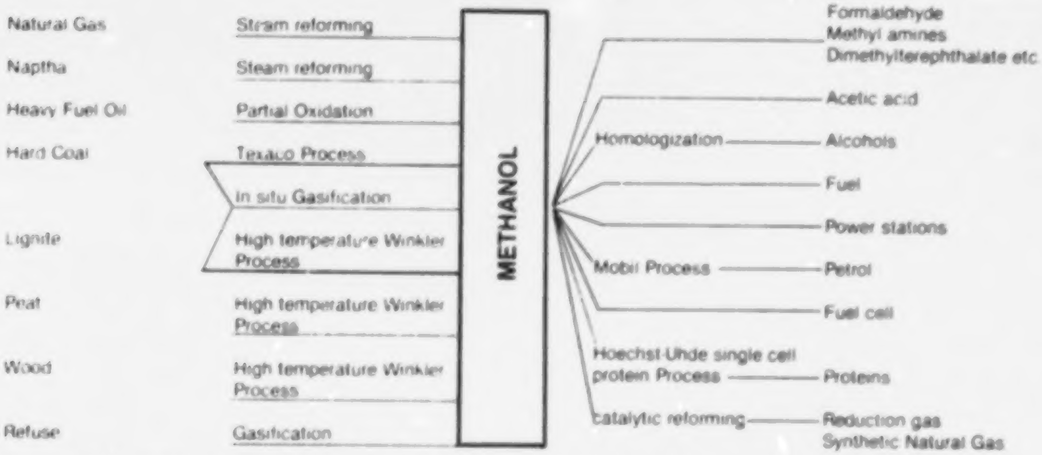

Natural Gas
Steam reforming
Naptha
Steam reforming
Heavy Fuel Oil
Partial Oxidation
Hard Coal
Texaco Process
In situ Gasification
Lignite
High temperature Winkler Process
Peat
High temperature Winkler Process
Wood
High temperature Winkler Process
Refuse
Gasification
METHANOL
Formaldehyde
Methyl amines
Dimethylterephthalate etc
Acetic acid
Homologization
Alcohols
Fuel
Power stations
Mobil Process
Petrol
Fuel cell
Hoechst-Uhde single cell protein Process
Proteins
catalytic reforming
Reduction gas
Synthetic Natural Gas

Figure 1 Productions and applications of methanol

In the light of the current discussion of alternative and renewable sources of energy, biomass and refuse also deserve consideration as raw materials for methanol synthesis.

As yet, the main application of methanol has been as a chemical feedstock, but interest has now focussed on the use of methanol as an alternative or an additive to automotive fuels, i.e., as secondary energy for the transportation sector. Huge methanol synthesis plants would, however, be required even if only 15% methanol was added to motor vehicle fuels.

World methanol production is currently some 14 million tonnes per annum. Because of the new applications for methanol which are currently under consideration, it is expected that production capacity may increase as much as tenfold within the next ten to fifteen years. The increase may be even greater if the use of methanol for the pipeline transportation of coal proves to be technically and economically viable.

According to [2] production costs of methanol based on mid-1980 West German raw material prices are as follows:

- Methanol produced from lignite (DM 17 per tonne): approx. DM 265 per tonne
- Methanol produced from hard coal (DM 170 per tonne): approx. DM 490 per tonne
- Methanol produced from natural gas (DM 6/GJ): approx. DM 290 per tonne
- Methanol produced from heavy fuel oil (DM 280 per tonne): approx. DM 380 per tonne

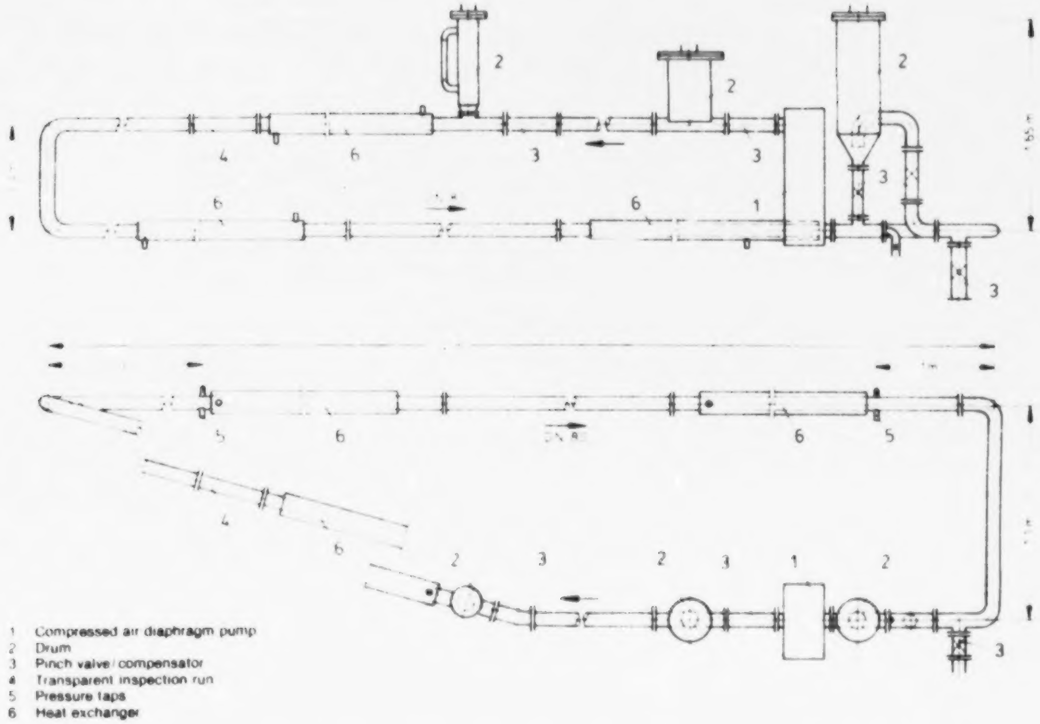
Taking into account an increase of 30% in the price of natural gas and an increase in the price of heavy fuel oil to DM 350 per tonne, production costs for methanol produced from these two raw materials would be DM 350 per tonne and DM 455 per tonne, respectively.

In the Federal Republic of Germany, methanol can be produced most economically from lignite, followed by natural gas and heavy fuel oil; hard coal is not competitive as a feedstock. Depending on price levels, hard coal could be competitive in other countries. If hard coal prices were of the order of DM 60 to 70 per tonne, production costs of methanol from hard coal would be DM 290 to DM 310 per tonne.

In 1981, the average price of methanol in the Federal Republic of Germany amounted to approx. DM 460 per tonne fluctuating between DM 270 and DM 600 per tonne as a function of plant size. Under these conditions methanol could be used economically as a source of energy if it were produced in sufficiently large plants.

4. Laboratory and Test Loop Tests With Coal/Methanol Mixtures

The test loop had to be designed to take into account the properties of methanol. The loop (Fig. 2) was constructed as a completely closed circuit of DN 80 pipes with a double-acting compressed air diaphragm pump (1). An axial or centrifugal pump was not used as this would have required liquid seals. Drums (2) were installed to compensate the volume and pressure fluctuation caused by the pump; these were half filled with nitrogen to prevent the formation of an explosive oxygen-methanol mixture. In order to prevent air from entering the system during filling operations, the coal bin (2) located at the suction site of the pump was pressurized with nitrogen and coal was filled in through an inlet in the cover of the bin.


2
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3
2
3
1
2
3
1 Compressed air diaphragm pump
2 Drum
3 Pinch valve / compensator
4 Transparent inspection run
5 Pressure taps
6 Heat exchanger

Figure 2 Test loop for experiments with coal-methanol mixtures

Heat exchangers (6) consisting of DN 125 casings with water flowing through the annular space were installed to keep the system at a constant temperature.

The throughput was regulated by means of a pressure control valve located in the compressed air line to the diaphragm pump. Compensators (3) were installed to minimize vibrations introduced into the system from the pump. Events inside the line could be observed through an observation run (4), consisting of a transparent perspex pipe section. Pressure measurements were taken at pressure taps (5) using piezoelectric crystals.

The experiments on the test loop were intended to determine pressure losses during transportation as a function of particle size and coal concentration in the slurry. Two types of coal were used for the tests:

- Dried high-volatile coal (density 1.33 g/cm^3, particle size variable, but as small as possible (cf. Table 2)).

- Dried or non-dried lignite (density 1.16 g/cm³, mean particle size 1.6 mm)

TABLE 2
DATA OF THE HIGH VOLATILE COAL USED FOR THE TESTS (FROM THE MONOPOL MINE)

Lot	1		2		3	
Particle Size mm	by mass %	Ash content (dry) %	by mass %	Ash content (dry) %	by mass %	Ash content (dry) %
3.15	11.12	27.85	—	—	—	—
3.15 to 2.0	23.09	26.13	—	—	—	—
2.0 to 1.0	28.90	26.81	—	—	0.09	3.53
1.0 to 0.8	8.65	33.04	—	—	0.65	3.53
0.8 to 0.5	11.68	39.85	0.77	6.67	9.12	3.59
0.5 to 0.315	7.20	40.81	2.69	5.86	26.07	3.34
0.315 to 0.125	5.86	48.27	17.66	3.75	43.03	3.85
0.125 to 0.063	1.30	57.50	21.00	4.81	7.91	9.53
0.063 to 0.045	0.28	52.04	8.71	6.93	1.86	12.96
< 0.045	1.92	68.79	49.17	16.78	11.27	29.05
Volatiles (dry + ash free) by mass	37.28 %		35.43 %		34.21 %	
Mass	227 kg		215 kg		225 kg	

The exact reproduction of the particle size distribution of the coal transported in the Black Mesa Coal Pipeline, USA, proved to be impracticable. With regard to practical applications, it also seemed unrealistic to prepare large quantities of very small particle sizes (< 20 μm) as recommended in American publications. For this reason, high-volatile coal with random particle sizes from the Monopol mine as small as could be obtained from normal screening process was used for the tests. Tests were carried out using both methanol and, for comparison purposes, water as carrier media, under the same experimental conditions.

Because of the hygroscopic properties of methanol, water is absorbed from coal thus producing a water-methanol carrier liquid; as it is not possible to dry coal completely in practice, tests were also carried out using coal-methanol-water mixtures in varying concentrations to simulate actual operating conditions.

Prior to the test loop work, preliminary tests were carried out in the laboratory; the main results were as follows:

- Coarse coal (mean particle size 130 μm or 500 μm) and even fine particles (with a mean size down to 20 μm) precipitate relatively quickly and can easily be separated from methanol by filtration.

- Fine particles (mean size less than 20 μm) form a relatively stable suspension with methanol.
- The properties of hard coal are not changed by exposure to methanol under simulated operating conditions (simulated by 120 hours at 60 bar in an autoclave agitator).
- The swelling properties of coking coal are not changed by exposure to methanol.
- Methanol does not react with lignite or hard coal. Lignite from the Fortuna Nord mine, 60% and 10% moisture content, and high-volatile coal from the Monopol mine were used for the tests. In the lignite tests, less than 0.5% of organic matter was found in the methanol phase of the suspension; in six-day experiments at 20 - 25°C using hard coal, the methanol phase of the methanol-hard coal suspension contained only 0.4% of low molecular weight organic impurities.
- Lignite swells in methanol, forming a paste; this process is even more marked at temperatures in excess of 50°C, with the result that viscosity increases sharply.
- Accelerated corrosion takes place in the presence of water.

The test loop tests showed that pressure losses occurring during the transportation of pure methanol were lower than those for pure water. This may be explained by the lower surface tension, density (0.81 g/cm^3 at 0°C) and viscosity of methanol at normal temperatures, as compared to water.

Tests with suspensions of coarse coal (lot 1) in methanol resulted in pressure losses which were almost always higher than those for pure water and coal-water slurries. Pressure losses for a coal-water slurry containing approximately 30% coal by volume were approximately equal to those for a coal-methanol slurry containing 20% coal by volume (Fig. 3).

The highest pressure losses were obtained for slurries consisting of pure methanol and large volumetric concentrations of coal. Tests with the same coal in suspension with methanol and water gave pressure losses for a coal content of 40% by volume equal to those for a water-coal slurry containing 20-30% coal by volume.

In the course of the tests it became clear that pressure losses for a constant 40% by volume suspension of coal in methanol decreased as the tests progressed (Fig. 4).

This phenomenon is explained by reduction in the particle size of the coal due to exposure to methanol.

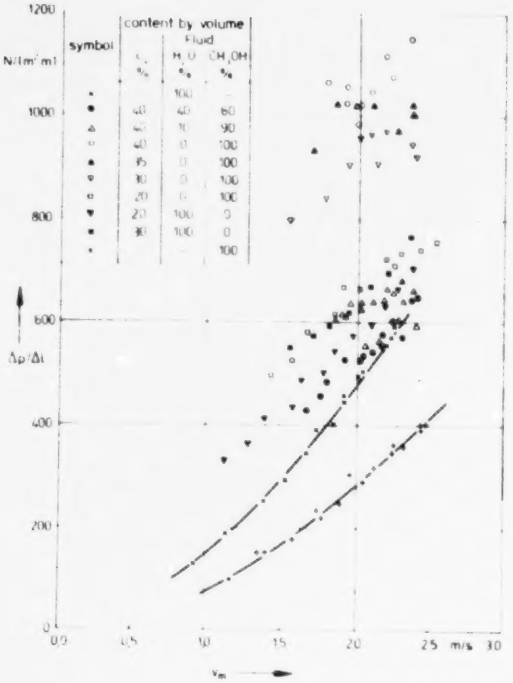

Figure 3 Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for coal-water, coal-methanol and coal-water-methanol mixtures transporting coarse coal (lot 1) c_v = % coal by volume

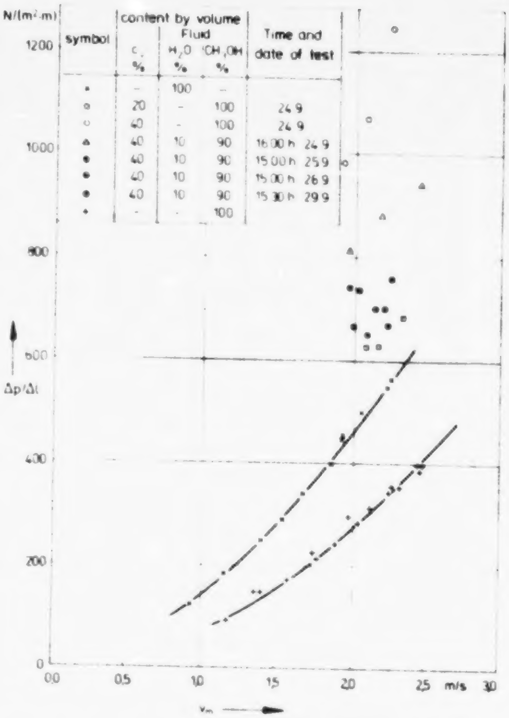

Figure 4 Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for coal-methanol and coal-water-methanol mixtures transporting coarse coal (lot 1) after various times in suspension c_v = % coal by volume

Pressure losses for suspensions of medium grained coal (lot 3) in methanol and methanol-water mixtures were between those for pure water and pure methanol (Fig. 5). The pressure gradient for a suspension of this type of coal in water closely approximated that of pure water and has not been shown, for the sake of clarity. Finally, the suspension of the finest coal used for this test (lot 2) in methanol showed the characteristic behaviour of homogeneous suspensions (Fig. 6).

During the tests with lignite, there were initial problems with starting the pump, because it proved difficult

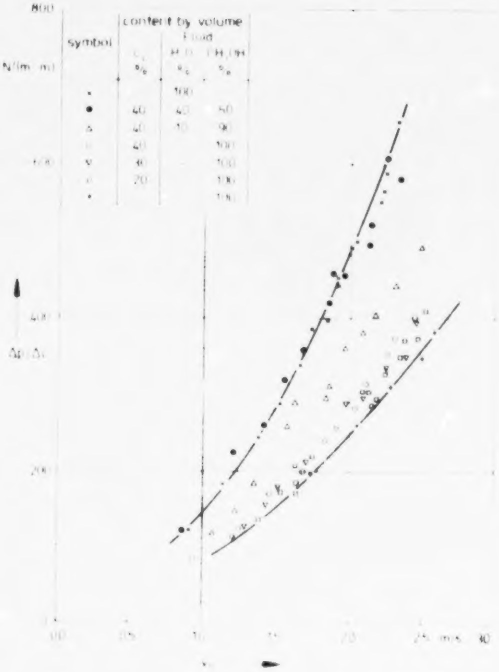

Figure 5 Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for coal-methanol and coal-water-methanol mixtures transporting medium-grained coal (lot 3)
c_V = % coal by colume

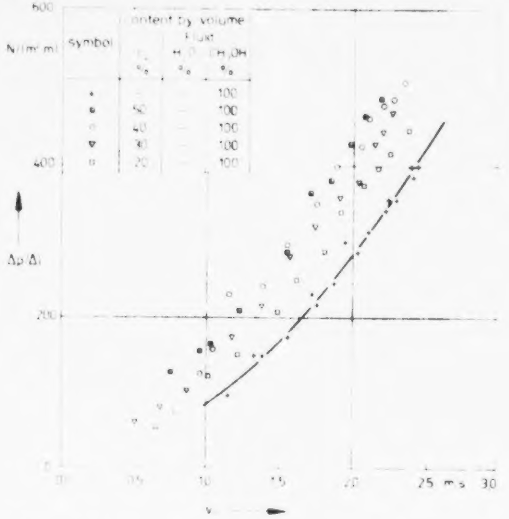

Figure 6 Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for coal-methanol mixtures transporting fine coal (lot 2)
c_V = % coal by volume

to force the lignite sediment back into suspension. The behaviour of the lignite-methanol suspension was similar to that of homogeneous suspensions, where slurry pressure loss curves deviate from those recorded for the pure liquid, and critical velocities are very low (Fig. 7).

5. Theory and Practice

The results of tests using water as a carrying medium showed good agreement with the theoretical values predicted. The methanol tests only showed good agreement for suspensions with low coal contents. As mean particle size and coal content increased, pressure loss fell increasingly short of the values predicted. Adapting the theoretical predictions to the test results, this phenomenon must be due to a progressive reduction in particle size due to the swelling and disintegration of coal particles in methanol, a hypothesis supported by the long term tests with Lot 1 coal and the laboratory tests with lignite. Disregarding this phenomenon, Fig. 8 shows that, for a pipeline with an outer diameter of 457.2 mm and a wall thickness of 8.6 mm, the minimum pressure loss for methanol-coal mixtures occurs at considerably higher pressure losses and considerably higher velocities than for water-coal slurry with the same coal content and properties. The behaviour of coal-methanol slurries approaches that of coal-water slurries if the particle size of the coal suspended in methanol is approximately half that of the coal suspended in water. The pressure gradient for both types of slurries then reaches nearly the same optimum value at approximately the same, moderate velocity.

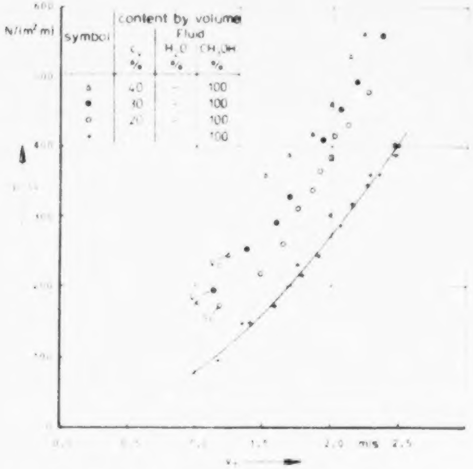

Figure 7 Pressure gradient $\Delta\rho/\Delta\iota$ as a function of velocity υ_m for lignite-methanol mixtures
c_V = % lignite by volume

Figure 8 Theoretical pressure gradient curve for the hydraulic transportation of coal in water and in methanol in a pipeline with an outler diameter of 457.2 mm and a wall thickness of 8.6 mm. $\Delta\rho/\Delta\iota$ = pressure gradient; υ_m = velocity; ω = percentage coal by mass and c_V = percentage coal by volume. Curves 1 to 3 were calculated on the basis of a mean particle size of 0.3 mm. Curve 4 was calculated on the basis of a reduced mean particle size of 0.17 mm

The theory for calculating the pressure loss is therefore valid for methanol-coal slurries if calculations are based on effective particle size. The optimum particle size for coal to be transported in methanol is 100-300 μm; together with the finest particles these particles then form a stable suspension of the pseudohomogeneous type.

6. Viability

A comparison of the cost of coal-methanol pipeline transportation with different modes of energy transportation, such as coal transportation by rail, coal-water pipelines, barges and power lines on the basis of 1981 prices shows that the cost per kilowatt/hour of energy transported is lowest for coal-methanol pipelines[3].

This result is due to the inherent advantages of pipeline transportation and the fact that methanol is itself a source of energy.

7. Prospects

The tests have shown that the pipeline transportation of coal-methanol suspensions is technically feasible and has certain advantages if coal with particles sizes of about 100 μm is transported. Coarser coal can also be transported but the particles then disintegrate during transport. Because of the hazards presented by methanol, the whole design of a pipeline system for the transportation of methanol-coal slurry, particularly the head station and terminal, would have to be different from that of a coal-water pipeline. For example, certain components would have to be sealed off.

As the freezing point of methanol is very low, methanol pipeline systems could be used for the rich coal fields of Alaska, Canada and Russia which are located in permafrost areas, i.e., regions where all the advantages for such a system can be utilized. The energy required for transportation could be taken from the medium itself.

The quantity of methanol required for a large modern pipeline would, however, exceed the capacity of the largest methanol plants currently available. On the other hand, methanol demand is still relatively low. As the cost of methanol is relatively high, it would probably be uneconomical to fire a coal-methanol mixture in power stations. The coal and the methanol would have to be separated and the methanol either pumped back to the head station or used as a chemical feedstock.

In the short term, coal-methanol pipelines will therefore probably only be used in exceptional cases, if methanol demand is not drastically increased, for example by laws encouraging the use of methanol as an automotive fuel. Such developments could be accelerated if dependence on oil producing countries reaches an intolerable level.

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The project was supervised by Technischer Überwachungsverein (TÜV) Rheinland in Köln.

The author was project manager of this study for Fried. Krupp GmbH, Krupp Industrie- und Stahlbau, Duisburg.

Questions on Paper by Gödde

Q: Did you include the cost of producing the methanol?

A: We took into account the 1981 price of methanol: 460 marks per tonne.

Q: What was the price of the methanol sold at the end of the pipeline?

A: That was not included in the study.

Q: Do you mean it was a transportation study, not a power generation study?

A: Yes. It did not include mining or other costs.

Q: How is the methanol returned?

A: It would not be returned, but rather is to be considered as part of the energy delivered.

Roehl: Basic Concepts of Hydraulic Capsule Pipelining A Review of the Work Performed at the Alberta Research Council

Basic Concepts of Hydraulic Capsule Pipelining
A Review of the Work Performed at the Alberta Reseach Council

A.A. Roehl, Head, Chemical & Materials Engineering
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Abstract

The transport in liquid filled pipelines of large cylindrical or spherical containers filled with grains, coal or other commodities, or capsules cast from sulphur, coal or municipal waste has been studied at the Alberta Research Council. The experimental program is summarized and the concept developments and results are discussed. Emphasis is given to the development of mechanical equipment requirements as envisaged to make an operating capsule pipeline a commercial reality.

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1.0 Origin of Hydraulic Capsule Pipelining at A.R.C.

In 1948 during the operation of a semi-commercial pilot plant to extract oil from the Athabasca oil sands, two problems were encountered. One was the transport in pipes of a heavy viscous crude oil mixed with water, the other was to dispose the sand tailing from the plant. A project was started to guide the designers of the plant in these problem areas. Laboratory work was continued in the transport of slurries in pipeline and relationships established for critical flow velocities, solids content, temperature and pipe diameter.

With the developing of oil fields producing heavy or viscous crudes, and the need to move these to refineries or markets, experimental work began in 1957 to study the behavior of two phase flow of two immiscible liquids in a pipeline, heavy or viscous oil and water. Analytical and experimental tests were done in stratifed flow, bubble flow and concentric flow. During concentric flow, it was possible to move a core of viscous oil in an annulus of water with a drastic reduction in energy requirements.

During the experimentation with two immiscible fluids flowing concentrically in a one-inch transparent pipe it was observed that several stable flow regimes were possible before the less stable concentric flow was reached. The two hydrodynamically stable regimes constituted of large spherical bubbles of a liquid in the second or carrier liquid and an increase in the input ratio caused the bubbles to coalesce and form large stable slugs, (c.f. figures 1 and 2). In most of the studies, the two liquids used were oil and water. This gave birth to the concept of hydraulic capsule pipelining studies at the Research Council[1]. It was envisaged that these bubbles could be encapsulated with an impervious skin or container and the enclosed liquid replaced with a commercial bulk commodity or the commodity itself be cast into one of these forms. Experimental and theoretical investigations in hydraulic capsule pipelining were started at the Research Council in 1958 with the first publications in 1962[2].

After the formulation of the hydraulic capsule pipeline concept and before extensive laboratory studies were undertaken, an initial evaluation of the economic potential was made. Power requirements and commodity preparations were considered for both slurry and capsule systems in this projection of solids transport in pipelines. Studies indicated that energy requirements per ton of material transported was less for capsules than slurries because threshold velocities for capsule systems are lower than the

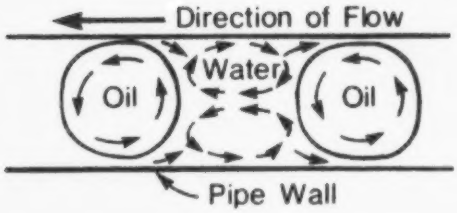


Figure 1 Liquid movement in the oil-bubbles-in-water flow pattern

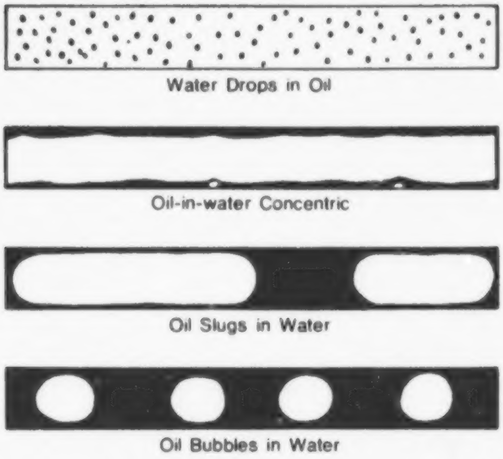


Figure 2 Flow configurations of oil and water in a pipeline

critical velocities for slurries of the same bulk density[3] [4].

Results from initial economic investigations were sufficiently encouraging to start an extensive pilot study.

2.0 Pilot Plant Test Facilities

2.1 1¼ Inch Diameter Pilot Pipeline

Early studies were done in a 1¼ inch diameter by 36 foot long acrylic pipeline. This facility was initially used to study flow characteristics and velocity ratios of the capsule velocity to the average velocity of the carrier liquid[5]. Temperature and viscosity effects were recorded[6]. A schematic diagram of the laboratory pipeline is shown in Figure 3 and capsules used in Figure 4. As experience was gained and as fast responding, sensitive and accurate pressure transducers were obtained, pressure gradients of the liquid only and liquid and capsule systems were measured and correlated with measured velocity ratios and specific gravities of the capsules and carrier liquid[7]. Synchronized photographic equipment was also installed to record simultaneously the hydrodynamics of capsule and carrier liquid in both the vertical and horizontal planes[8].

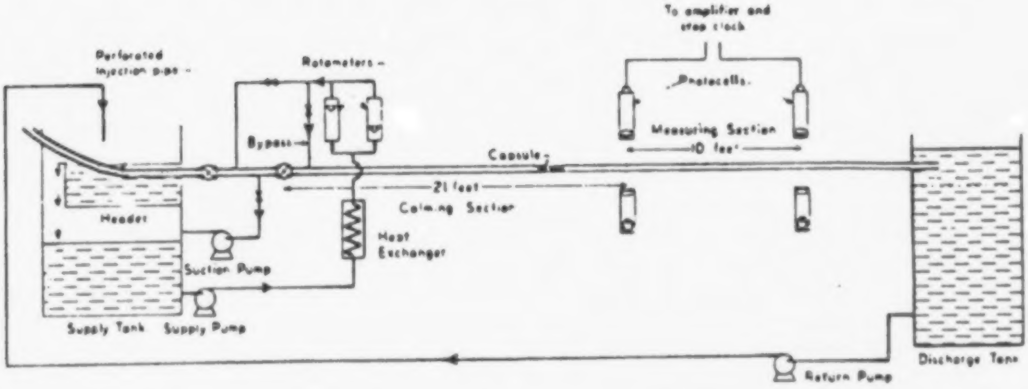

To amplifier and
stop clock
Perforated
injection pipe
Rotometers
Photocells
Measuring Section
10 feet
Bypass
Capsule
21 feet
Calming Section
Header
Heat
Exchanger
Suction Pump
Supply Tank
Supply Pump
Discharge Tank
Return Pump

Figure 3 Schematic diagram of the 1⅛" capsule pipeline

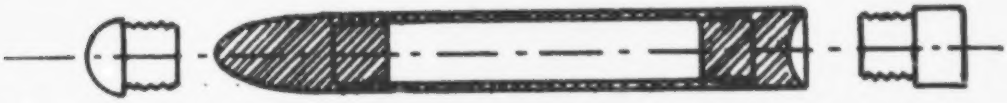


Figure 4 A typical hollow, plastic, cylindrical capsule, with alternative ends

2.2 Vertical - Continuous Belt Pipeline

To understand the hydrodynamics of long capsules or a long continuous train of capsules, a continuous neoprene circular cross-section belt was constructed and run in a one inch diameter, thirty foot long vertical pipeline. Liquid velocities and linear belt velocities were varied, measured and recorded. The direction of the belt could be reversed. Some difficulties were encountered due to the elasticity of the belt which in turn created a small but significant variation in the cross section of the belts. The variations of the belt diameter to pipe diameter ratio was detected in the pressure gradient readings, creating errors with numerical values equal to, or greater than the true values measured. The experiment provided a good insight into the established flow patterns in the annular space between a long capsule and the inner pipe wall[9].

2.3 ⅜ Inch Demonstration Pipeline

A small ⅜ inch inside diameter by 48 foot long continuously operating pipeline model was constructed to experiment with valve switching. An interesting feature of this system was the section of the pipeline which permitted inclination from horizontal to ninety-degrees to the horizontal. Spherical and cylindrical capsules were pumped around and their behavior studied as they moved through the inclined section. No hard data was collected from this system. It, however, provided design data for other laboratory equipment.

2.4 Inclined Facility

To better evaluate capsule effects on inclines, an apparatus was constructed containing four pipe diameters. (c.f. Figure 5). The largest pipe diameter was two inches, others were one inch, one-half inch and three-eighth inch. Cylindrical and spherical capsules of various diameters and specific gravities were inserted, the apparatus inclined to the required angle and the liquid velocity adjusted until the capsule assumed a stationary position relative to a preselected mark on the pipe wall. Liquids of various viscosities were used over a wide temperature range providing a broad range of viscosities. Capsule behavior was documented, pressure gradients for liquid and liquid/capsule systems measured and suspension velocities recorded. An interesting observation was that spheres went into an oscillating motion at several angles of inclination. A gentle rocking motion of the spheres was observed at low angles; they then remained stationary to angles greater than 55 degrees while a bouncing motion was observed at angles between 55 and about 80 degrees. At angles near 90 degrees the spheres tended to gently rotate around the inner pipe wall without making contact[10]. Correlations of sphere behavior and angle of inclination provided an understanding into the behavior of spheres moving up inclines in a hydraulic pipeline system. It can be deduced that no serious problems are anticipated on the average pipeline grade or inclines less than 50 degrees.

2.5 Pipeline Loop for Paste Slugs

In all early investigations, except the ¼ inch facility, capsule experiementation was in single pass pipelines. As hydrodynamics of capsule systems were better understood and it was felt that masking effects of operational valves could be isolated, several one-inch closed loop continuous operating pipelines were constructed. The first of these was a 30 foot loop used to study the behavior of coal paste slugs[11]. (c.f. Figure 6). The coal was finely comminuted and mixed with water to a consistency resembling a stiff paste, formed into cylindrical capsules and injected into the pipeline where they were transported in an oil carrier. Trains of these slugs were manufactured and transported in the loop while all the parameters of interest were recorded, including photographs of the slug behavior. Many paste consistencies were prepared, and some were stabilized with agar. When a run or series of tests

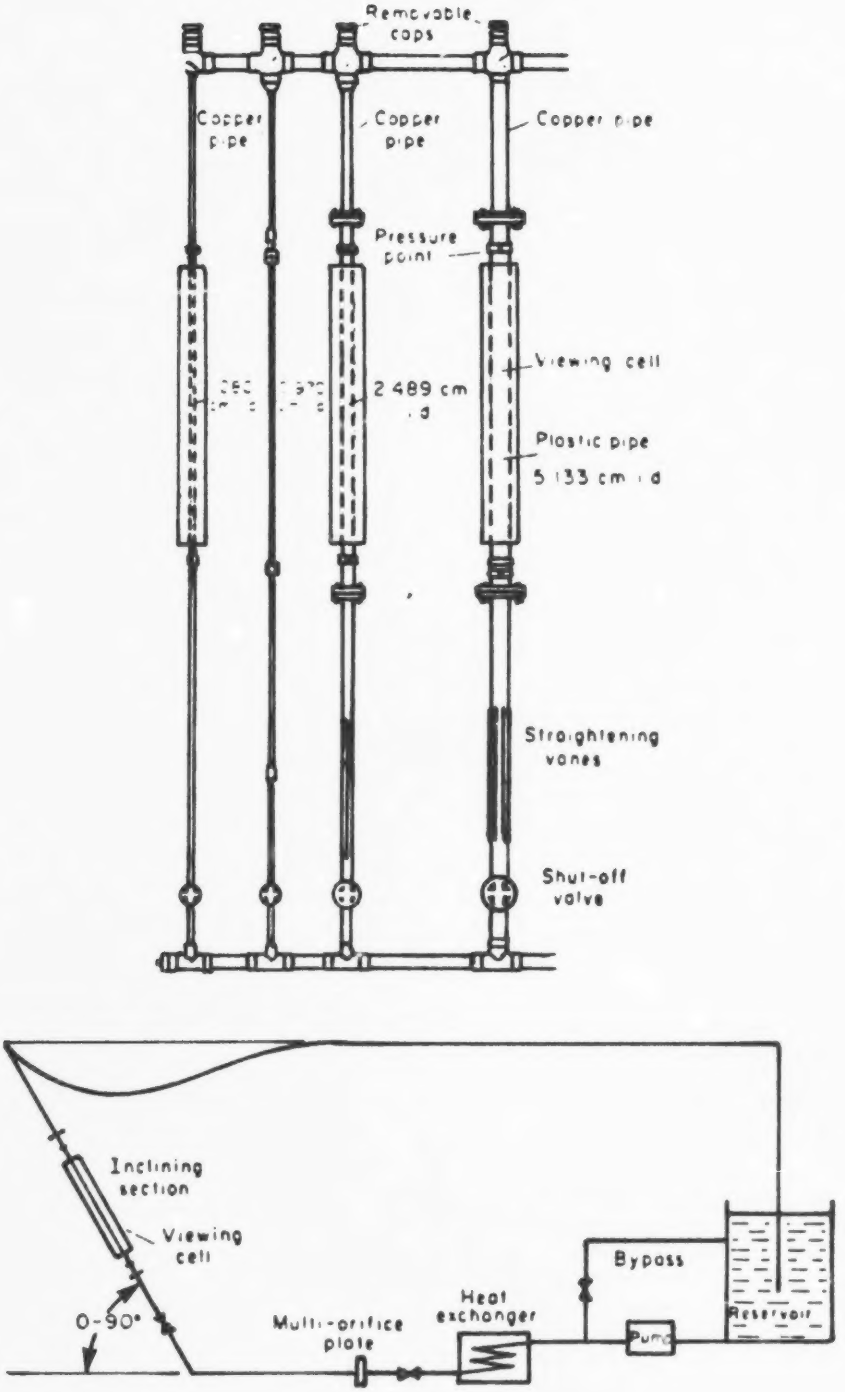
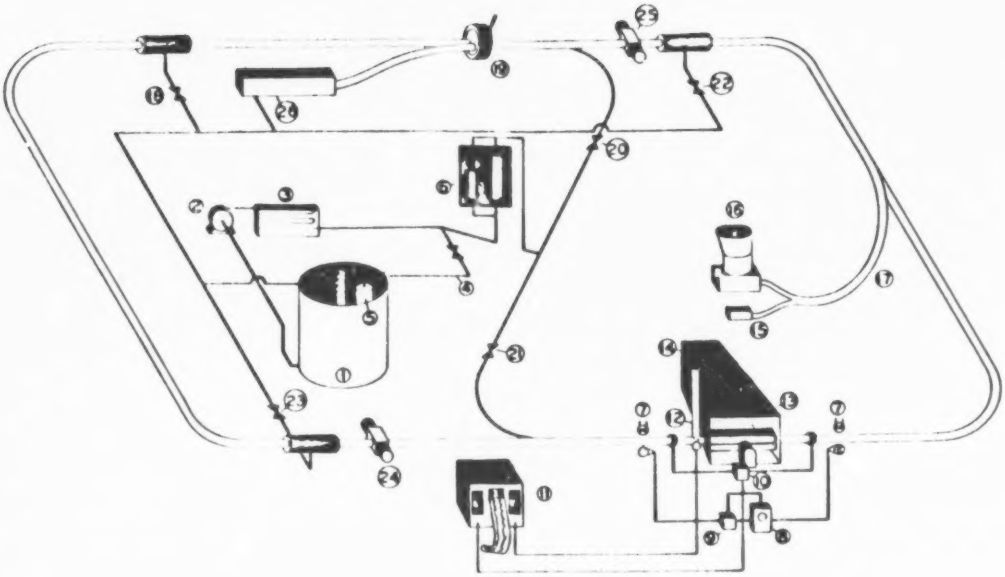

Removable caps
Copper pipe
Copper pipe
Copper pipe
Pressure point
Viewing cell
2.489 cm i.d
Plastic pipe
5.133 cm i.d
Straightening vanes
Shut-off valve
Inclining section
Viewing cell
0-90°
Multi-orifice plate
Heat exchanger
Bypass
Pump
Reservoir

Figure 5 Capsules for 1¼" laboratory experimental line



List of Components

1. Oil storage tank
2. Pump (centrifugal)
3. Heat Exchanger
4. Return line
5. Glass-wool filter
6. Rotameters
7. Photocell assembly (velocity)
8. Millisecond clock
9. Latching relay
10. Differential pressure cell
11. Two channel recorder
12. Photocell assembly (spacing)
13. Photographic unit
14. Camera location
15. Hand injector
16. Screw extruder
17. Holding line
18. Auxiliary withdrawal chamber
19. Diverting switch

20-21-22-23
Solenoid operated globe valves

24-25
Full flow sliding valves
(solenoid operated)

26. Slug collection chamber

Figure 6 Schematic Diagram of Test Loop for Paste Slugs

was completed, the train and oil were ejected on a screen which retained the slugs while the oil was filtered to remove any broken slugs before it was returned to the main reservoir[12].

Results obtained from these experiments indicated that the coal paste slugs were quite stable and could withstand rigorous activities while in the pipeline. This was later verified when a similar test was done in a four-inch inside diameter by 3,900 foot long steel pipeline.

2.6 Continuous Operating Pipeline Loop

A second one-inch closed loop facility was constructed to study the behavior of mechanical systems such as multi-valve switching over long periods of operation. A schematic diagram of the operating system is shown in Figure 7.

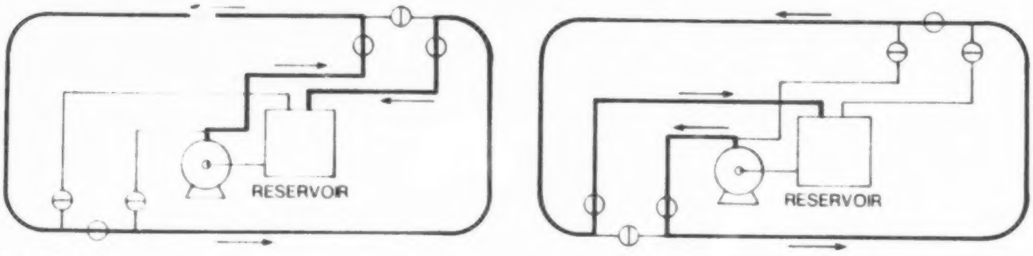


Diagram A

Diagram B

Diagrams A and B indicate potential methods for bypassing the liquid pumps.

Figure 7 Laboratory Loop Bypass

An additional thrust was to observe capsule behavior in a train and how the component capsules of a train could be made to stay together without physically linking them or severely prejudicing the normal behavior of the train with the use of heavy lead capsules. A slight increase in the specific gravity of the lead capsule in a train of cyclinders was effective without detectable changes in pressure gradient. Spheres tended to space themselves approximately one diameter while transported on the horizontal plane. They spread apart on declines, and gathered on inclines. Steep grades or inclines created severe bunching and oscillations of the tail sphere of the trains.

2.7 Four Inch Shuttle Line

A four inch inside diameter by 200 feet long steel shuttle line was constructed and operated to provide data for scale-up effects[13]. For details see schematic drawing in Figure 8. Design parameters were calculated from the small laboratory lines and predictions were postulated from the results obtained from the bench scale pipelines. As the facility was not continuously operating, emphasis was on experimental data to define the hydrodynamics of capsule systems comprised of spheres and cylinders of varying specific gravities and surface roughnesses. It became evident in the larger pipeline that surface effects were more pronounced. That is, high specific gravity cylinders with rough surfaces required higher threshold velocities before they started to move and increased pressure gradients to keep the train moving along the pipeline were required.

Spheres with irregular surfaces tended to bounce and slide with random spacing while smooth well rounded spheres rolled along the pipe, spacing themselves approximately one sphere diameter apart.

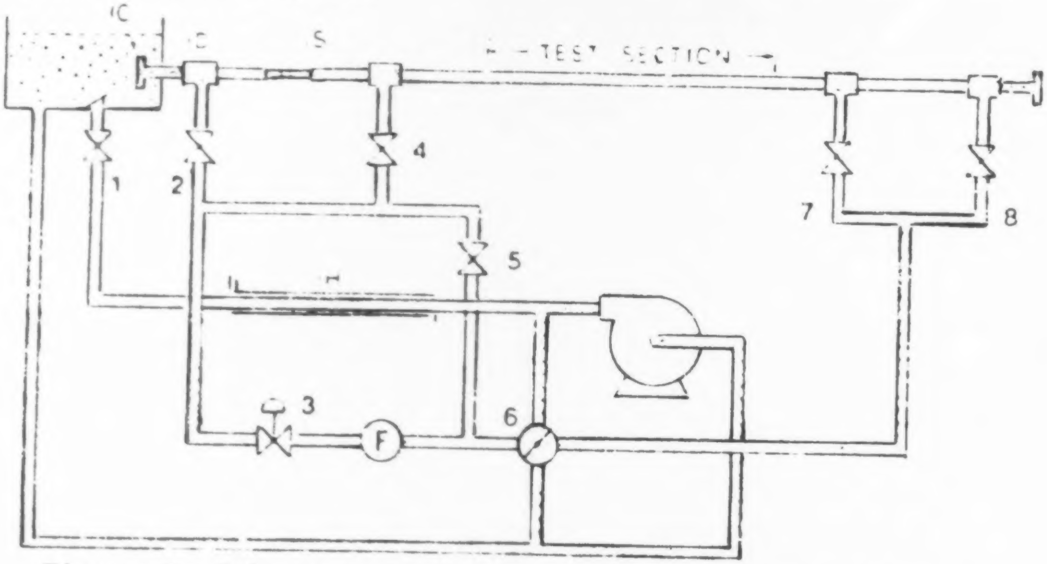


Figure 8 Schematic diagram of typical capsule shuttle pipeline test facility

A surprising but very useful phenomenon was realized when granular salt particles escaped into the pipeline from the water removal system in the oil reservoir. Several days and a number of runs were repeated in order to solve why pressure gradients suddenly were only about 25% of the values measured for earlier runs of a given capsule liquid system. It became apparent that the salt granules tended to provide a lift effect and reduced the contact between capsule surface and pipe wall. The results were most pronounced when high specific gravity cylinders were transported at slow velocities.

3.0 Capsule Design Program

Early programs in capsule surface modification were by changing the geometric shapes and adding runners and collars. These changes produced encouraging effects.

3.1 Capsule Collars

A systematic investigation was launched into methods of reducing pressure gradients with the addition of collars[15]. It became apparent that thin collars, 1/16 to ⅛ inch thick, and less than two inches wide when placed in the front half of a cylindrical capsule, provided encouraging pressure gradient reductions by lifting the capsule from the pipe wall and locating it in an axial position in the pipeline. Details are shown in Figure 9.

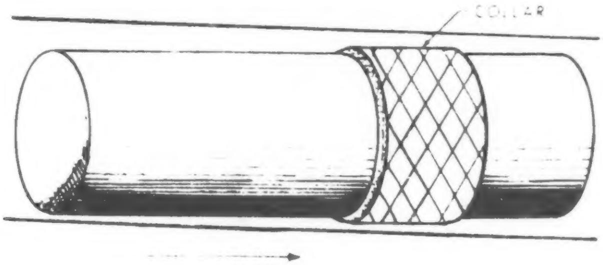


Figure 9 Cylindrical capsule with collar

3.2 Geometric Variations

End configurations were also varied from square end to elliptical noses and concave tail ends on cylinders but the reduction in pressure gradients or the increase in capsule to carrier liquid velocity ratios obtained did not reflect the additional effort in the capsule design.

3.3 Surface Effects

Surface roughness of the capsule-pipeline system were investigated[16]. The surface of the capsules was modified by machining well defined finishes on cylindrical capsules and comparing them to identical capsules having very smooth micro finishes. Test sections of the pipeline were also interchanged to obtain variations in pipe roughness effects. That is smooth pipes, pipes constructed from different materials and lined pipes were inserted and wear effects were analyzed by visual inspection, measurement and weighing. Surface effects were less pronounced when low specific gravity cylinders were used or when the velocity of the carrier liquid was increased. Less energy was required to move smooth cylinders in a smooth-walled pipe than in pipes with rough or non-uniform inside walls.

3.4 Liquid Additions

During the capsule surface modification program, a short test was performed with the addition to the carrier liquid of a number of long chain polymeric compounds which had been used for the reduction of friction in pipeline systems. A negative effect was experienced as the threshold velocity was increased and the capsule velocity to liquid velocity ratio decreased. This had the effect of the capsule train moving slower for a given liquid velocity. Pressure gradients for the capsule liquid system also indicated marginal increases due to the increased liquid velocity.

4.0 Field Test Facilities

As the data base for capsule pipelining was expanded, additional economic studies were performed based on the developing technology. The results obtained by ARC and other researchers made it increasingly evident that a capsule pipeline system had advantages over a slurry pipeline by requiring less energy to move a given volume of a bulk commodity.

To demonstrate the technical feasibility of capsule pipelining, a consortium of 22 industrial companies was formed and along with the Federal Government Department of Industry and Commerce (Program for Advancement of Industrial Technology - P.A.I.T. program) a four inch diameter, 3,900 foot long continuous operating pipeline facility was funded, constructed and operated. The Solids Pipeline Research and Development Association (S.P.R.D.A.) not only funded the construction and operation of the test facility, but also funded a number of consultants for independent technical feasibility and economic evaluations of the concept.

4.1 S.P.R.D.A. Project[17]

The test facility included capability to operate with capsule trains one hundred feet long and longer, had data collection points on a five degree incline, a five degree decline, a 125 foot diameter pipe loop and one horizontal test section, c.f. Figure 10. The program provided for the operation with cylinders and spheres of a wide range of specific gravities, two diameters, flexible cylindrical containers and paste slugs constructed from coal (using first water and later oil as the carrier liquids). The results from earlier laboratory tests and the field data were provided to the consultants for input to their studies.

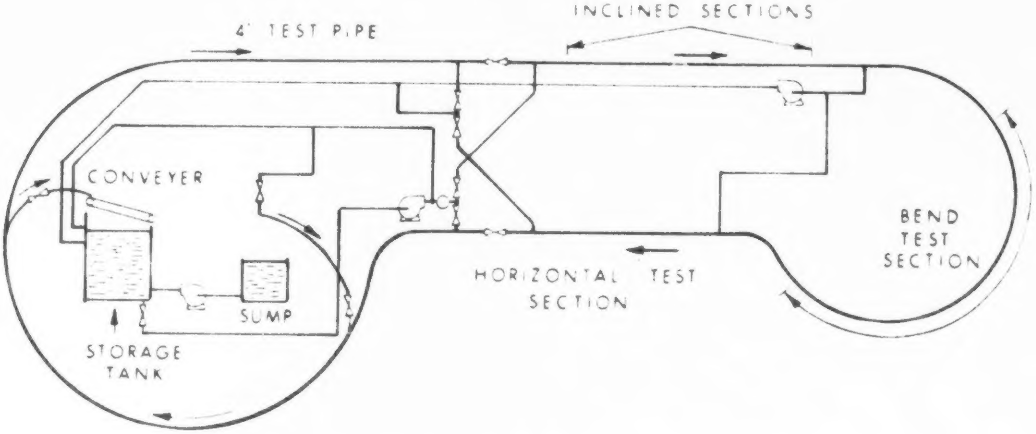


Figure 10 Schematic Diagram of Four Inch S.P.R.D.A. Pipeline Loop

4.2 T.D.A. Pipeline Project

The decline in interest in pipelines in the late 1960's and early 1970's and insufficient funding available to build a ten inch diameter by several miles long full scale demonstration capsule pipeline facility terminated full scale equipment development. ARC then decided to construct a 400 foot long, 10 inch diameter automated shuttle line,[18] see Figure 11. Also a battery of shorter pilot plant lines ranging in size from one inch to four inches in diameter were built[19]. (c.f. Figure 12). These two facilities provided excellent means to study scale effects in capsule design and increased the data base for the hydrodynamics of hydraulic capsule systems. This three year program was funded by the Transportation Development Agency (T.D.A.) of the Ministry of Transport. The results of the investigation were reported including a system analysis of the capsule pipeline concept[25] [26].

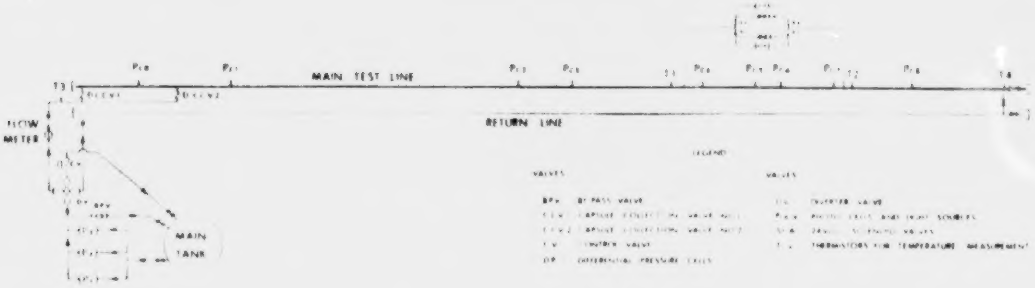

MAIN TEST LINE
RETURN LINE
FLOW METER
MAIN TANK
LEGEND
VALVES
VALVES

Figure 11 Schematic Diagram of the Ten Inch Pipeline

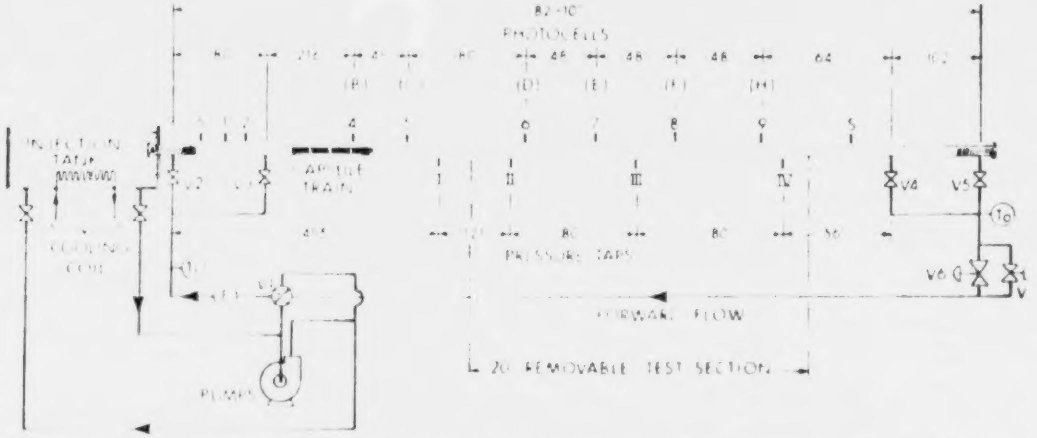

PHOTOCELLS
INJECTION TANK
COOLING COIL
CAPSULE TRAIN
V2
V3
V4
V5
V6
PRESSURE TAPS
FORWARD FLOW
20' REMOVABLE TEST SECTION
PUMPS

Figure 12 Schematic Diagram of Laboratory Shuttle Pipeline

5.0 Components of a Hydraulic Capsule Pipeline System[20 21]

A capsule pipeline system is more complex and has more components than a liquid pipeline. Initially there is capsule preparation followed by the injection of the capsules into the pipeline. The pipeline must be smooth, have gradual bends and have sufficient bypasses or booster stations and retrieval systems at the destination. With the increased number of components, operational logistics and instrumentation become significant to the operation of the facility.

A capsule pipeline can transport a considerable amount of material. Table 1 indicates the tonnages of material that can be carried annually by a ten inch pipeline operating with a capsule velocity of 4.5 feet per second, an 80% linear linefill and a capsule to pipe diameter ratio of 0.89.

TABLE 1
CAPSULE PIPELINE CAPACITY

Commodity	Specific Gravity	Throughput MM Tons/year
Coal	1.23	1.30
Iron ore (sphere)	4.50	4.52
Sulphur (sphere)	1.80	1.81
Potash	1.60	2.41

Linefill is probably one of the most important features in the capsule pipeline design since it limits the transport rate. Linefill is determined by the injection mechanism or bypass methods used. In earlier studies multiple-barrel systems were used; however, if inline systems are developed, a linefill in excess of 80% may be obtainable in commercial practice.

5.1 Potential Commodities

Commodities or materials which lend themselves to transport in a hydraulic capsule system are summarized in the following table.

TABLE 2
POTENTIAL COMMODITIES

Product	Type of Capsule
Coal	Cylindrical container or compressed paste slug
Sulphur	Cast cylinder or cast sphere
Potash	Cylindrical container or paste slug
Mineral Ores	Sintered cylinders or spheres
Wood Pulp	Compressed cylinders
Grains	Cylindrical containers
Municipal Waste	Compressed cylinders
Other Materials	Cylindrical containers

5.2 Capsule Preparation

During experimental investigations capsules were classified according to shape -- spheres and two types of cylinders -- conventional and modified. The modified cylinders involved the addition of collars to gain hydrodynamic advantages in transport. However, a classification based on the method of capsule preparation is more appropriate for pipeline design. Capsules can be filled, cast or compressed. Filled capsules are those that have a shell which is filled with a commodity while cast capsules are made by solidifying a liquid material or by recrystalizing solids into capsule form. Compressed capsules are formed by extrusion, pelletizing or piston compression methods.

5.2.1 Filled Capsules

A number of factors, both mechanical and economic, enter into the choice of the container. The container can be rigid or flexible. However, the major factor affecting selection is the disposition of the container -- whether the container is to be discarded or re-used; returned to be refilled or recycled if sufficient markets are available. If plastic containers are used, they can be recycled into other products. This method provides not only transportation for the prime commodity, but also transport for a second commodity, potentially enhancing the economics of transportation.

Rigid containers have the advantage of handling and ease of closing and can be used for a variety of different commodities. They can also be loaded to different degrees volumetrically to control the capsule density. If granular or freely flowing materials are the commodity used then the operation of filling will not be much different from currently used, established procedures.

Raw materials such as grain, coal, sulphur or potash pellets or metallic ore concentrates might be shipped by filled capsule. Filled capsules are the most versatile, and almost anything that is non-perishable and that will fit into the capsule can be transported in this manner.

There are few requirements for cylindrical containers. They must, however, withstand the pressure of the pipeline and the impact that capsules undergo during the course of pipeline operation. Pressures of the pipeline system are known and can be accommodated in the design. Some shielding is provided by the liquid between capsules during impact; however, the stresses generated during impact have not been determined.

5.2.2 Cast Capsules

Materials which are produced in liquid form and can be cast into molds to solidify can be considered as candidates for cast capsules. Included are sulphur, potash and metallic ores. Metallic ores often are produced in powdered form and can be sintered into spherical or cylindrical forms.

A major consideration is the impact loading that materials can withstand in their solidified form. Some like sulphur are brittle and must be modified or protected by some form. This type of capsule resolves the problem of capsule return or recyle.

5.2.3 Compressed Capsules

Included in this classification are those that are either extruded or compressed to increase their density and improve their stability. The transport of selected municipal waste to a distant landfill site or a power plant in capsule form can be accomplished economically and resolve many environmental problems. However, sufficient material must be available for an economic system[22].

5.2.4 Capsule Characteristics

Experience has shown that capsules must be larger than 50%, preferably 80 to 90% of the pipe diameter and that the optimum length for cylinders is about five times the capsule diameter. Hydrodynamically it may be advantageous to add collars to rigid re-usable containers to provide lift from the pipe wall and attain a more axial position in the pipeline.

5.3 Injection Facilities

A ten inch pipeline transporting capsules at an average velocity of 4.5 feet per second requires that one nine inch diameter by 3.7 to 4 foot long capsule weighing approximately 150 lbs. be prepared and injected into a high pressure system in one second; or 5 nine inch diameter spheres to provide the same linear linefill. This is a difficult task. If larger systems are used or the pipeline is operated at higher velocities, the task of preparing and injecting capsules becomes more difficult, but not impossible. Most studies, including the studies carried out during the S.P.R.D.A. project, indicate that multiple capsule preparation facilities are required and that multi-barrel injectors be used.

In Figure 13, the sequencing of loading and unloading injector barrels into a high pressure capsule pipeline are shown. The general procedure is to connect one injection barrel to the capsule fabricators while a second barrel is emptied into the pipeline. The number of injector barrels required is determined by the number of capsules which a barrel will hold and the frequency with which barrels can be switched into the pipeline.

Operation of multiple barrel systems requires valves to control the liquid flow and diverters to control the capsule movement through the pipeline network. A number of diverter designs have been proposed over the years. Mechanical diverters are shown in Figure 14 and a fluid diverter shown in Figure 15. The speed or operation of these devices also has an impact on the linear linefill that can be attained.

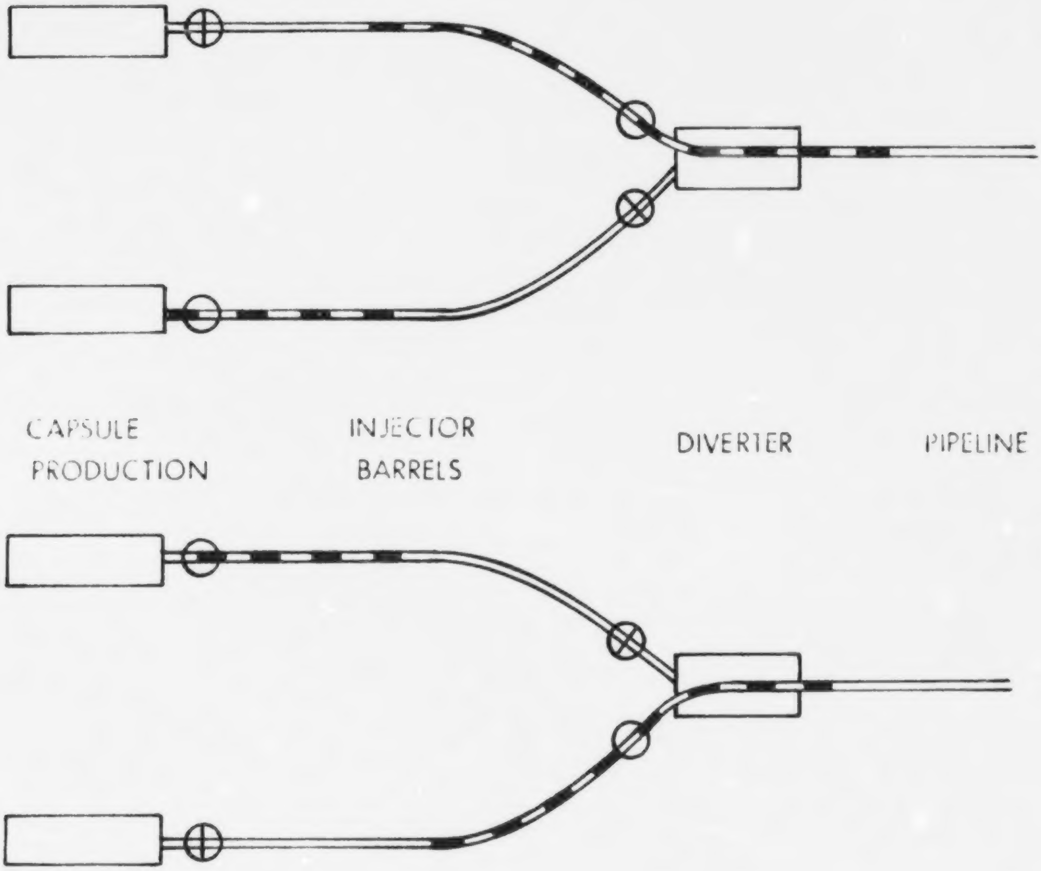


Figure 13 Two Barrel Capsule Injector

5.4 Pipeline

The difference in design requirements between a conventional liquid or gas pipeline and a capsule pipeline are minor. Design parameters for pressure are well established and need not be modified. Three criteria which must however be observed during design of a capsule pipeline are that the cross sectional area of the pipe remains round and that bends in the pipe must be uniform and of a radius sufficiently long to permit the passage of capsules. A third requirement is that no weld protrusions are permitted at joints. In large diameter pipelines, these can be removed by grinding and in smaller diameter pipes, consumable rings can be used as spacers to prohibit penetration of the weld into the inside of the pipeline. This is an established procedure often used in gas pipelines. Any inline valves must be full port full opening.

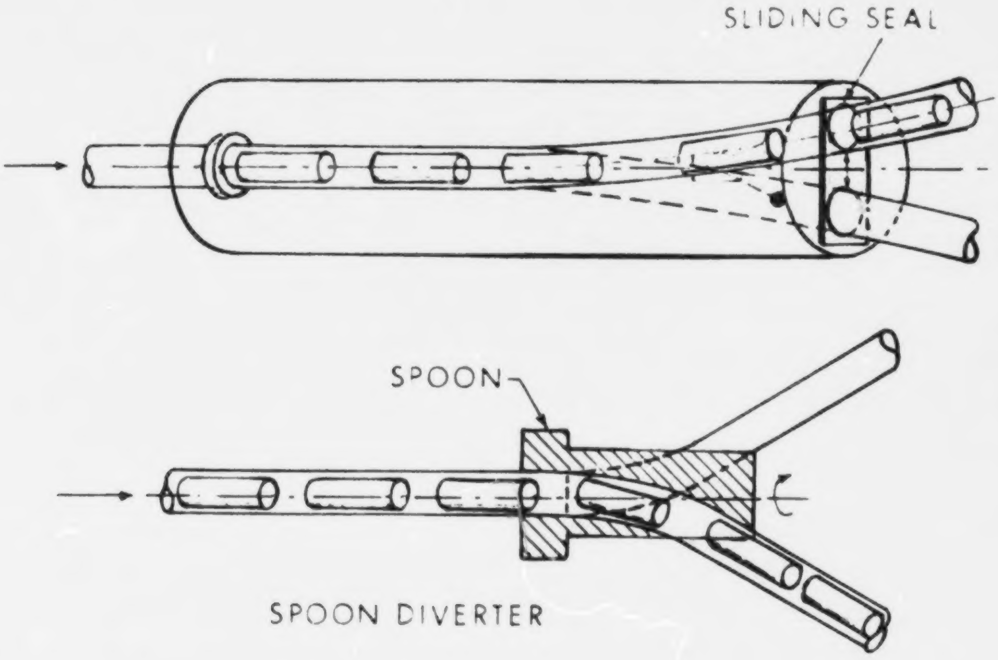


Figure 14 Mechanical Diverters

5.5 Bypass Facilities

In all but short lines, the design of booster stations or pump bypass stations are necessary to repressure or provide additional energy to the system to move the capsules and fluid to the destination terminal. This can be done by shunting the capsules around the pump while the liquid is passed through the pump. A schematic of this bypass system is shown in Figure 16. The parallel leg bypass system is similar to an injector where one barrel is charged while the other barrel of the system is discharged. However, this method is not very efficient since it requires the stopping and sudden accelerating of capsule trains.

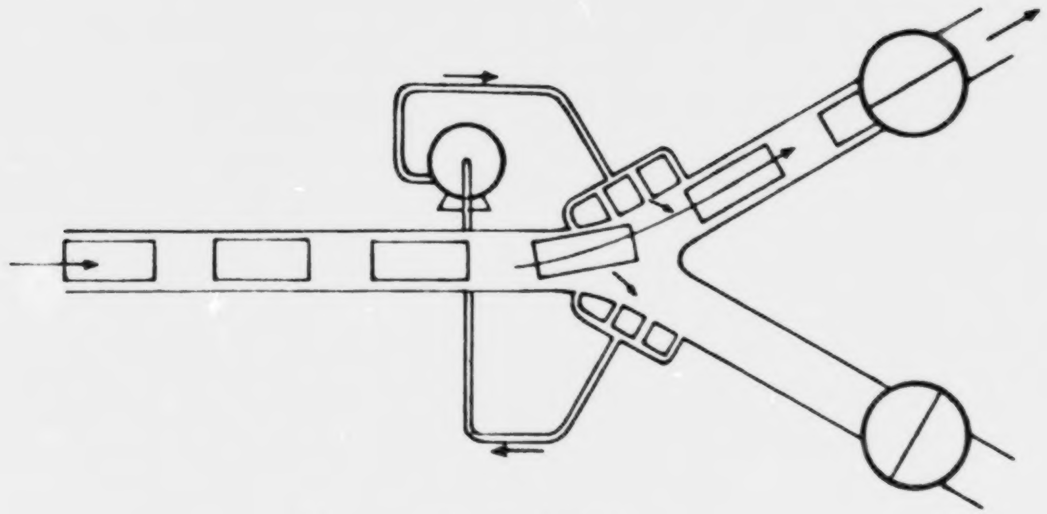


Figure 15 Fluid Diverter

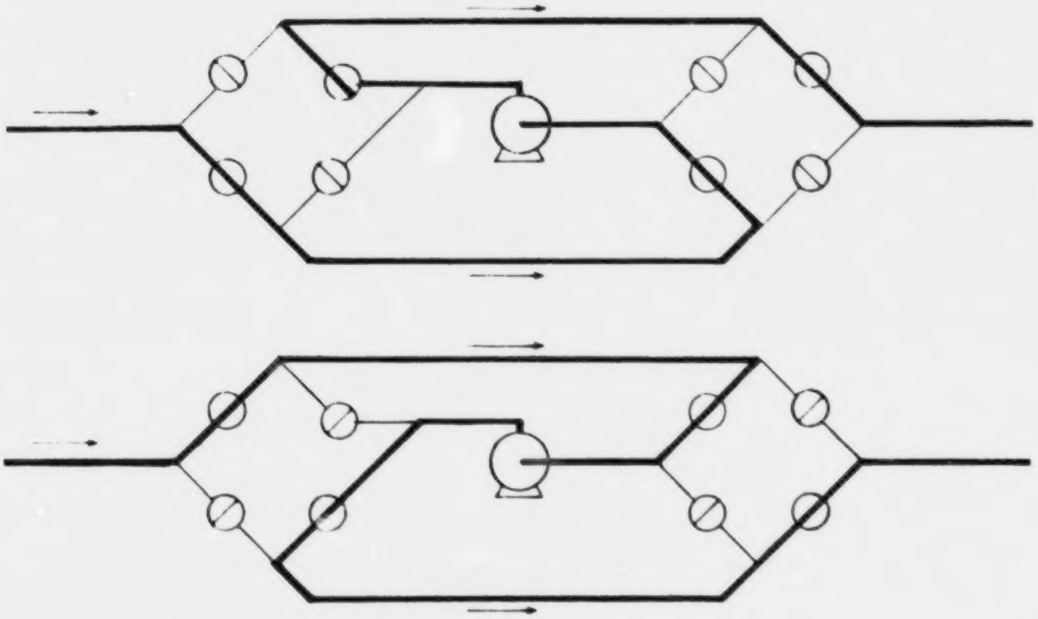


Figure 16 Bypass Schematic

A number of in-line pumps have been considered and experimentally tried. (See Figure 17). The most common is the venturi accelerator with the vortex accelerator, a modification of the same principle. These are well known.

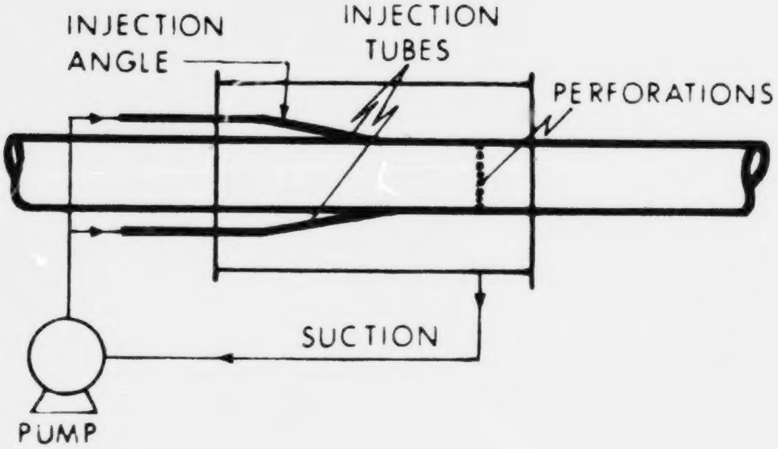


Figure 17 Inline Capsule Pumps

Two in-line vane pumps operated at ARC are shown in Figure 18 for cylinders and in Figure 19 for spheres. The two are basically similar in that the capsules are introduced into the vane pump one at a time and while in the pump pass from the low to the high pressure side of the pump. Additional energy is supplied with an external high pressure pump system. The rate of rotation of the vane pump is determined by the velocity of the capsule train. Two major concerns about vane pumps are apparent. The first requires that the capsules trains must be controlled to permit only the entry of one capsule at a time. The second is the sealing requirements for each vane are demanding and high pressures on the external case must be overcome to facilitate sealing of the carrier liquid.

New, innovative thinking is required for this part of the system if capsule pipelines are to become an economic commercial reality. It is my understanding that we will be introduced to such a system during this workshop.

5.6 Retrieval Facilities

Retrieval of capsules from a capsule pipeline system does not appear to present a difficult task. The pipeline effluent can be discharged onto a moving screen conveyor and the liquid drained into a reservoir while the capsules can be cleaned, if necessary, and continue their journey to their destination. Processing of capsules downstream from the retrieval area depends on the ultimate use of the commodity being transported, and the container itself. In the case where containers are to be re-used, they must be

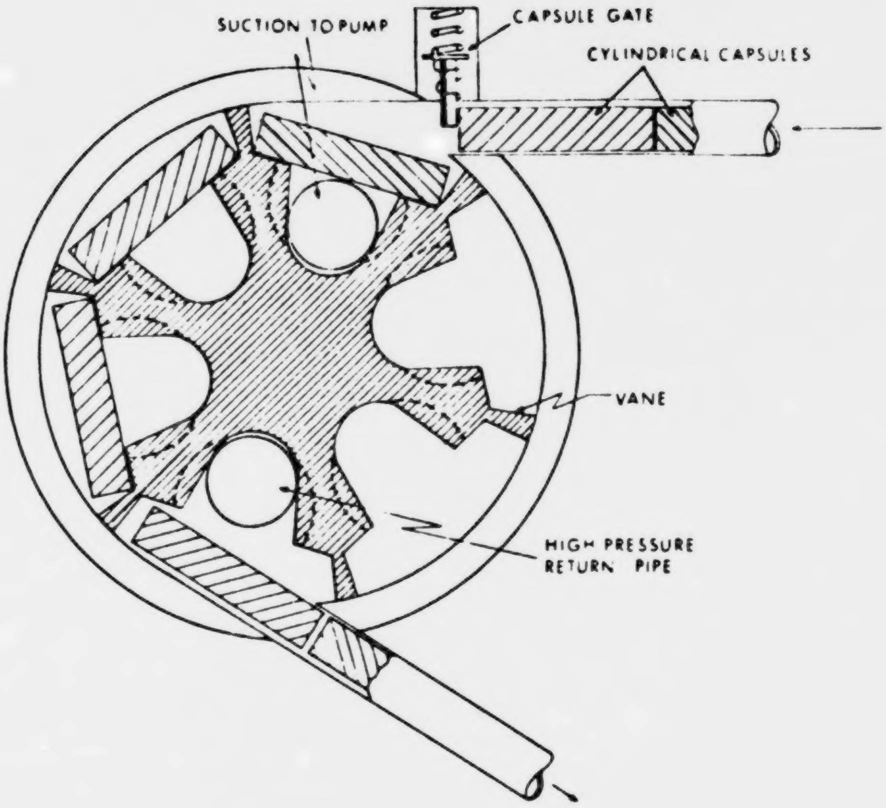

SUCTION TO PUMP
CAPSULE GATE
CYLINDRICAL CAPSULES
VANE
HIGH PRESSURE RETURN PIPE

Figure 18 Vane Bypass Device - Cylindrical Capsules

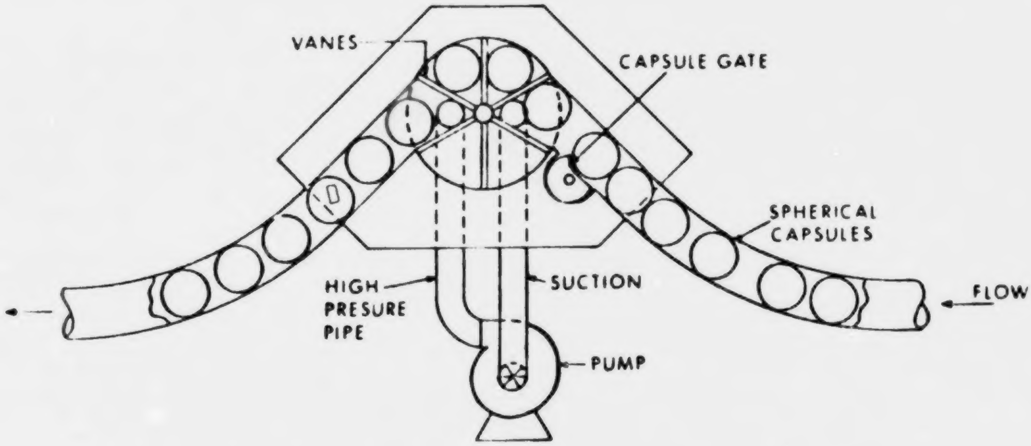

VANES
CAPSULE GATE
SPHERICAL CAPSULES
FLOW
HIGH PRESURE PIPE
SUCTION
PUMP

Figure 19 Vane Bypass Device - Spherical Capsules

emptied and prepared for return to the source. Where containers are to be recycled into other products, the capsules must be emptied and the containers dispatched for further processing. Capsule handling equipment at the pipeline terminal would probably be similar to the equipment at the pipeline origin, only the injector tubes would be replaced with conveyors.

Depressuring of the pipeline at the terminal may pose a problem where there is a large decrease in elevation just before reaching the destination. In this case, means of dissipating the kinetic energy must be engineered into the system. This can be accomplished with a controlled orifice.

5.7 Instrumentation

Capsule pipelines will require sensing devices to detect capsules within the pipeline, their relative positions and velocities. Sequencing logic for computer control to permit the sequential operation of various pipeline components is essential. This in turn will be controlled by signals from telemetry equipment which would evaluate the system operations. Changes in capsule distribution in the pipeline system can change the loading requirements at downstream by-pass stations.

The utility of a capsule pipeline can be increased if the solids throughout can be controlled by controlling the capsule distribution in the system.

If a capsule pipeline is to become a common carrier, meaning it carries various commodities, then some means of differentiating between capsules is essential. This can be accomplished with a "tag" built into the capsule, color coded, or other characteristics. A triggering device which can differentiate between capsules will activate diverters to separate the different commodities at the downstream terminus.

During valve switching and diverting of capsule trains, designers must be recognize the need to minimize surges or shocks to prevent damage to the pipeline or to the capsules in the system. Experimental tests have shown the presence of capsules in a pipeline have an attenuating effect on surges or water hammer, thus diminishing the magnitude of the problem.

6.0 Summary[23] [24] [25] [26]

Experimental equipment and design investigations indicate that capsule pipeline systems are technically feasible and indications are that they are economically competitive with other modes of overland transportation. Refinement in capsule handling and pump by-pass systems or booster stations will greatly enhance the attractiveness of hydraulic capsule pipeline transportation of high bulk, low unit cost commodities.

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Questions on Paper by Roehl

Q: Is this research published?

A: It has been published.

Q: Is your test loop still in existence?

A: No. The actual work was done in 1967 and 1968. The concept has been proven technically . It is up to the industry to develop it further.

Q: Have the economics of capsule pipelines been updated?

A: No. But an industrial organization is interested in the technology for environmental reasons. An independent consultant has concluded the system is economically feasible. Additional development work should improve the economics of the system.

Q: World-scale plastics plants will be coming on-stream in Alberta during the next few years. Do you expect this to enhance the economic attractiveness of capsule pipelines?

A: Yes.

Q: Could saleable plastics be produced at the pipeline terminus?

A: We have not looked at this recently. It was considered when the original research was done.

Q: What kind of volumetric throughput could you get with a capsule system?

A: About 80 per cent linear fill could be attained but in the field tests trains of capsules up to 100 ft long were tested.

Q: I heard this system described at a conference at Banff, Alberta, and I was impressed by it. Would it be difficult to export the capsules on ships or to return them to the origin - like with a slurry line? Since this would be a new system, it would be quite risky to make the large investment required to construct a capsule pipeline. Were you looking at the possibility of recycling the plastic capsules?

A: The Alberta Research Council did not do much work on that aspect. The industrial organization I mentioned earlier is currently doing extensive research on plastic encapsulation of coal for domestic and export markets.

Q: If the capsules take up 85 to 90 per cent of the pipe diameter, isn't deformation in the capsule a problem?

A: No. We didn't encounter this.

Comment (participant)
Pneumatic systems and other systems also separate the carrier medium. In Germany, we also have a magnetic levitation system. Due to environmental concerns, our mine waste cannot be transported anymore with trucks. We have no room for more railways. Slurry pipelines are being considered, but they have the dewatering problem. Capsule pipelines have met a fair amount of resistance due to the reluctance of "old hands" to commit to new technologies. He recognized the problems posed by the empty containers but seemed to believe plastic sacks might present a solution to this problem, although capsule to pipe diameter ratios would have to be kept high to ensure the sacks did not override one another and plug the line.

Shook: Dense Coal Slurries

Cliff A. Shook, Chemical Engineering University of
Saskatchewan, Saskatoon

Dr. Shook described research carried out to examine the slurry pipeline hydrodynamic properties of certain coal slurries.

Effects of concentration

A. Viscosity effects:

- Increased deformation.
  - A broader size distribution results in lower viscosity.
  - The geometry effect - the small particles hide between the large particles.
- Increased resistance to flow. This depends on the particle size distribution.
- The surface chemistry effect. Fine particles have a large surface area. Fluid is attracted to the surface of the particles, and is not available to lubricate the particle flow. This results in higher viscosity.

The energy required to transport two types of Alberta coal - Judy Creek Coal and Kaiser Coal were described. His experiment indicated very high density flow occurring at the bottom of the pipe and this suggested a means of determining ideal concentration.

B. Other effects:

- Concentration distribution of solid particles in the pipe.
- Velocity distribution of particles in the pipe.

We would like to be able to predict energy consumption for slurries. Additional research was presented to illustrate these other effects.

We want to predict velocities and concentrations at a particular point. There is strong experimental evidence that high concentrations can be achieved. It depends on the size distribution and the surface chemistry of the coal. Coals vary a great deal and therefore we cannot generalize.

Questions on Shook's presentation

Q: How were concentrations measured in the test program?

A: A gamma ray device was used to measure concentration from top to bottom in the pipe.

Comment: The best distribution appears to be occurring at the bottom of the pipe.

Comment: There is a need for iso-kinetic measurement to determine ideal grain size.

Q: Don't you think an approach to the question of determining the ideal size distribution for dense slurries should be approached in a more practical way by starting with user needs?

A: Yes, but my interest is science of pipeline hydrodynamics not economics.

Dense Coal-Water Liquids: Basis of a New Coal Chain?

W.A. Warfe, Energy, Mines & Resources Canada, Ottawa,
Ontario

Introduction

In 1981 total coal consumption in Canada approximated 40 million tonnes of which 78% was consumed by electric utilities. This high use of coal by utilities along with Canada's commitment to reduce Maritime utilities dependence on foreign oil renewed EMR's interest in coal-liquid mixtures; an interest that started in the early seventies.

Dense coal-water liquids (DCWL) appeared particularly attractive as an economical fuel for conversion of oil-fired boilers in the Maritimes not only as a means of reducing Maritime utilities dependence on foreign oil but also as a contributor to the mitigation of sulphur dioxide and nitrogen oxides (acid gases) emissions from utility boilers. Because of our early experience in this field we are now turning our interest to the broader implications of DCWL technology.

This discussion paper will focus then on the role of dense coal-water liquids in a possible new coal chain, that is, the production of a dense (>70% wt.) low viscosity coal-water mixture which could be produced, transported and used directly for combustion in stationary combustors under environmental restraints.

Short distance transportation of DCWL by rail, barge or road from production sources to users should not produce any major problems. However, long distance transport by pipeline raises several questions, namely:

1) Should the slurry line be run at 50% and densified at the delivery end or, efforts be made to run a dense mixture all the way?

2) Could normal (50-60%) and dense slurries be batched?

3) Can coal slurries be batched in any existing partially used or unused oil lines that may be available?

4) Should densification take place at our tidewater or at the customer's tidewater?

5) What problems exist in operating tankers carrying dense coal water mixtures?

6) What environmental problems are there?

These are key questions that must be answered, if we are to proceed with a broader development program. We also foresee some technical problems that may develop through freezing of the mixture and inadvertent gelling of the slurry in the ship hold.

Market Potential

Dense coal-water liquids could replace oil in many stationary combustion and in some mobile uses provided that they can be burned reliably, cleanly, safely and economically. Canada has underway programs (see attached Appendix) in support of this objective.

Domestically we currently see a market in eastern Canada where natural gas has not been generally available and local coal tends to be both expensive and high in sulphur. The need for replacement of imported oil is thus more urgent in eastern Canada, particularly for utility usage in both existing and new boilers.

Sales of DCWL fuel from a production plant in Cape Breton do not need the long distance pipeline issue to be resolved: we are starting there and can supply from there. Export markets could be supplied from ships loaded off-shore.

The establishment of a long distance dense coal slurry pipeline may offer cheaper transport at a more stable long term cost and thus increase export potential for western coals. Certainly a dense coal slurry will significantly reduce marine shipping costs without the added expense of end-of-the pipe dewatering costs and environmental restraints requiring water treatment facilities.

The specific use of dense coal-water slurries for utility boilers has the following advantages and disadvantages:

Advantages	Disadvantages
1. Lower capital cost for new plants. No grinding equipment nor storage hoppers required.	1. Liquid mixture may freeze creating handling and storage problems.
2. Greater flexibility in choice of fuel.	2. Derating of unit.
3. Acid gas emissions reduced by finer grinding and processing.	3. Extra grinding and processing of the fuel may make the fuel cost uneconomical.

Production and Preparation

Canada has a dense coal-water slurry program underway at Sydney, Nova Scotia. A fuel preparation plant of 4 tonnes per hour will be built to treat clean coal (-3 mm) from an adjacent conventional dense medium coal preparation plant which has as its design objectives the following:

Ash - less than 2% from 15% ash coal
Sulphur - less than 1% from 2.5% S coal
Mixture - 70% coal
Viscosity - less than 1000 centipoises
Coal to Fuel yield - over 80%
Thermal yield - over 90%.

Before large scale production can take place, answers need to be found to the following questions:

1. What coals will make a dense phase slurry? Our present experience indicates all bituminous coals can be handled. It is less known whether low rank coals could be used, even if it were economically attractive, due to their generally lower energy content.

2. What is the optimum grinding and processing allowed for various ranks considering existing market price of other fuels?

3. Can the dense material be produced from clean coal, or can you design dense coal mixtures to combine cleaning and densification?

It has been noted that coal drying is expensive and troublesome and therefore should be designed out of the process, if possible.

What Can Canada and FRG Do?

We can through this forum agree on research and development priorities then, approach suppliers, transporters and users to integrate each into a project that could involve long term contracts.

Some of the priority areas proposed are:

i) development and demonstration of reliable, safe, efficient burners;

ii) thorough study of the environmental impact from the mine to utilization;

iii) storage and handling; and,

iv) detailed pipeline studies to ensure a consistent product.

Conclusions

Preliminary indications are that dense coal-water slurries are feasible and that such a mixture has potential for transportation in a slurry pipeline. However, the following areas must be addressed:

1. Long distance issue with respect to dense versus normal slurries must be resolved and whether dense slurries can be batch transported or not.
2. The use of existing pipelines is desirable if capital costs are to be minimized. If not, long term contracts will be an absolute necessity to justify the enormous investment in new dedicated pipelines which in turn require very large (15 m tonnes) point-to-point movements of coal.
3. An integrated approach of producers, transporters and users is essential for the success of such a venture.

Finally, in conclusion, we would like to say that this workshop provides an excellent forum for an exchange of views on this new coal chain.

Appendix "A"

Energy, Mines & Resources
Coal Slurry Pipeline R&D

In this role of technology support to the various coal-liquid mixture projects that are being undertaken, the Canada Centre for Mineral and Energy Technology (CANMET) is involved in contract and in-house research to address the following key problem areas:

1. Burner development for coal-liquid mixtures including the study of abrasive wear of atomizer components.
2. Assessment of the potential loss of capacity (derating) when converting oil-designed boilers to coal-water mixtures.
3. Slagging and fouling assessments of coal-liquid mixtures in utility and industrial boilers and combustors.
4. Parameters for upgrading existing and designing new environmental control equipment for oil-fired boilers when converting to coal-liquid mixtures.
5. Combustion and heat transfer properties of coal-liquid mixtures in various combustion system configurations.
6. Upgrading coal quality by advanced cleaning techniques in order to minimize abrasive wear and to reduce environmental emissions of sulphur dioxide and fly ash.

Questions on Paper by Warfe

Q: Why such low ash specifications?

A: Burner erosion. The low ash content makes it similar to burning oil. It allows us to avoid the additional costs associated with burning coal in oil burners.

Q: Is there a BTU penalty?

A: We are trying to determine this. The National Energy Board has allocated $5.5 million for this research over the next four years.

Q: Western Canadian coals have a high ash content. Does this mean the same additives will be required to prepare coal methanol slurry and Carbogel with this coal.

A: Carbogel contains less than 2 per cent ash in order to combat burner erosion. The additives are added after the ash has been removed - to keep the slurry in suspension - not to reduce the ash content of the slurry.

Q: Is fine grinding required to eliminate ash?

A: Yes, it is.

September 28, 1982
MORNING SESSION

Husband: Pilot Scale Capability of Solids Pipeline Testing in Canada

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SLURRY PIPELINE DEVELOPMENT CENTRE
at Saskatoon

W.H.W. Husband, M. Small, R. Gillies, D. Haas, Saskatchewan Research Council, Saskatoon

C.A. Shook, University of Saskatchewan, Saskatoon

ABSTRACT

The Saskatchewan Research Council has been studying the transport of solid materials such as coal through pipelines since 1960. In 1970 Transport Canada and the Saskatchewan Research Council decided to capitalize on the facilities and expertises assembled at Saskatoon, and established the Slurry Pipeline Development Centre. The Centre has become an internationally recognized organization. Since 1976 all work has been carried out under contract. Test pipelines range from 50 mm to 500 mm in diameter and materials as varied as lignite coal, nickel concentrates and deepsea manganese nodules have been pumped through them. Current interest is in the transport of coarse coal slurries. Test loops, test procedures, and ways of using the experimental data are described.

INTRODUCTION

In 1960 the Saskatchewan Research Council (SRC) recognized the potential of pipelines to transport solid materials over long distances to processing plants or markets. Potash in vast quantities had been discovered in Saskatchewan. Markets, however, were 700 to 1000 km away. Rail freight rates were estimated to be as much as 50% of the ultimate cost to the consumer.

Against such a background, attempts were made to determine the technical and economic feasibility of potash pipelines from Saskatchewan to Vancouver and to the Chicago area. Lack of adequate basic engineering data soon became apparent and a decision was made to initiate a study of the hydraulic transport of solids through pipelines.

Staff of SRC and the University of Saskatchewan collaborated to construct and operate a small experimental pipeline loop in 1961. The loop was operated until 1965. The resulting experimental information was used to examine the mechanisms of solids suspension, to determine eddy diffusivities, and to develop equations for the pressure gradient along the pipe on an improved theoretical basis to replace previous empirical equations such as the Durand equation. By the end of 1965 experimental work on larger diameter pipeline loops was desired to verify the equations developed from the measurements on the original 50 mm line. An excellent beginning to large scale work was undertaken in 1966 when the Interprovincial Steel and Pipe Corporation and the federal government's Department of Industry, Trade and Commerce sponsored a three-year study of potash pipelining. During this period a building with 800 m^2 of floor space was acquired. Pipeline test loops with diameters of 150 mm, 200 mm, 250 mm, 300 mm and 350 mm were constructed and operated in this building.

In 1970 the Canadian Transport Commission (CTC) authorized SRC to carry out a three-year program to:

1. study the relative importance of the various candidate commodities for pipeline transportation in Canada,
2. analyse and undertake preliminary investigations of the problems of start-up and shut-down of commodity pipelines, on the erosion and corrosion in pipelines, and the effect of additives,
3. produce large scale slurry property data over a range of concentrations and particle sizes in pipes up to 300 mm in diameter,
4. accumulate and classify literature on solids pipelines for dissemination.

The objectives of the CTC program were to:

1. Provide the CTC and the Canadian public with appropriate technical information on the design of slurry pipelines,
2. encourage the consolidation of a Canadian team which could undertake meaningful and large scale research and development into the engineering design of slurry pipelines, and
3. provide universities with a basis on which they could develop better models of the physical mechanisms involved in transporting suspensions in pipelines.

The objectives were obtained on schedule and a series of nine reports was issued. Over 2,000 copies of these reports have been requested by industry from all parts of the world. Late in the program a reorganization in the Ministry of Transport created the Transportation Development Agency (now called the Transportation Development Centre) and located it in Montreal. This agency has been guiding the Slurry Pipeline Development Centre at Saskatoon through use of steering committees. Since 1976 the Centre at Saskatoon has been operating solely on a contractual basis without any provincial funding.

The initial cooperation between SRC and the University of Saskatchewan has continued through the years and has been a vital part contributing to the success of the Centre. In general, theoretical studies have been undertaken by graduate students under the direction of the Department of Chemistry and Chemical Engineering of the University of Saskatchewan, while the design, construction, and operation of experimental pipelines have been the responsibility of the engineers and technologists of SRC. More than 80 reports have been issued.

Pipeline Loops Available

The original 50 mm diameter pipeline loop has been replaced and the Centre now has 9 test loop systems with pipelines ranging from 50 mm to 500 mm in diameter. The systems are shown schematically in Figures 1 to 9.

The 50 mm test loop in Figure 1 is used for special studies such as pipe wear, use of unusual carrier fluids such as methanol, sodium chloride, calcium chloride or potash brines, and for concentration or velocity profile studies. The 50 mm test loop shown in Figure 2 is used in the preliminary stages of contractual studies. The loop does not require much material, is easy to operate, and allows the operators to determine quickly any unusual features of a particular slurry. The 50 mm test loop in Figure 3 is used for fluid flow studies involving heavy oils with wax crystals.

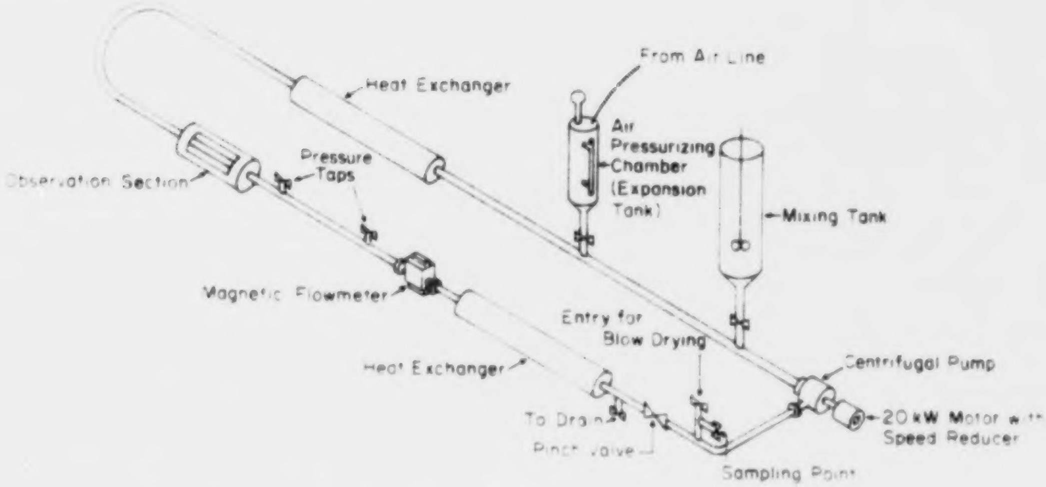

From Air Line
Heat Exchanger
Air Pressurizing Chamber (Expansion Tank)
Mixing Tank
Observation Section
Pressure Taps
Magnetic Flowmeter
Entry for Blow Drying
Heat Exchanger
Centrifugal Pump
To Drain
Pinch Valve
20 kW Motor with Speed Reducer
Sampling Point

Figure 1 Diagram of 50 mm closed loop line

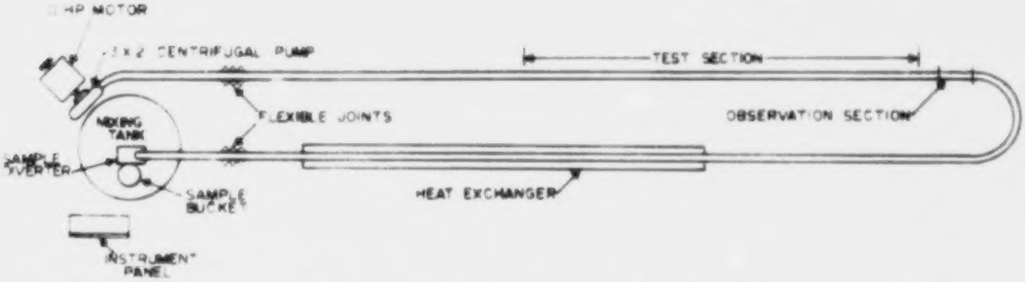

HP MOTOR
3 X 2 CENTRIFUGAL PUMP
TEST SECTION
FLEXIBLE JOINTS
OBSERVATION SECTION
MIXING TANK
SAMPLE DIVERTER
SAMPLE BUCKET
HEAT EXCHANGER
INSTRUMENT PANEL

Figure 2 50 mm open pipeline loop schematic diagram

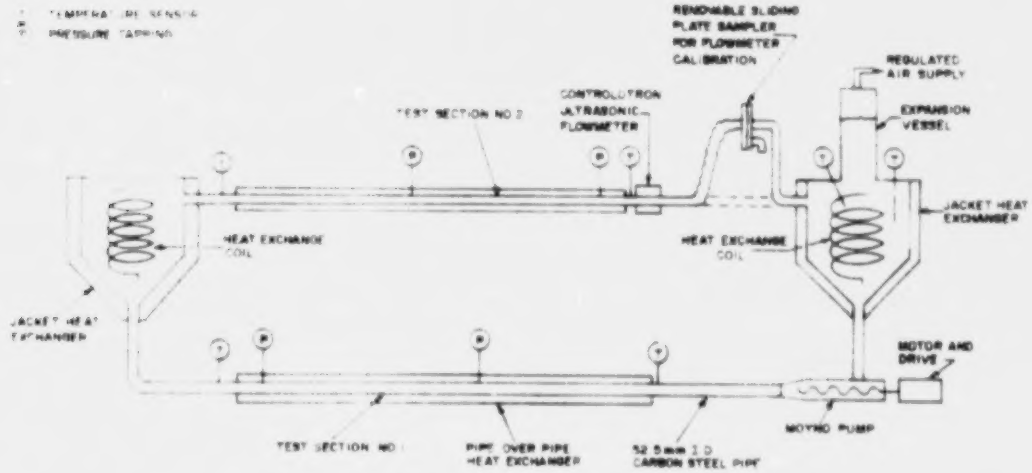

TEMPERATURE SENSOR
PRESSURE TAPPING
REMOVABLE SLIDING PLATE SAMPLER FOR FLOWMETER CALIBRATION
REGULATED AIR SUPPLY
CONTROLOTRON ULTRASONIC FLOWMETER
TEST SECTION NO 2
EXPANSION VESSEL
JACKET HEAT EXCHANGER
HEAT EXCHANGE COIL
HEAT EXCHANGE COIL
JACKET HEAT EXCHANGER
MOTOR AND DRIVE
MOYNO PUMP
TEST SECTION NO 1
PIPE OVER PIPE HEAT EXCHANGER
52.5mm I.D. CARBON STEEL PIPE

Figure 3 50 mm heavy oil test loop

The 100 mm test loop shown in Figure 4 is an intermediate sized test loop which is used when a client wishes to obtain hydraulic data on larger sized pipe but does not have a large quantity of his material. The 150 mm test loop of Figure 5 can be operated at any slope from 0 to 17 degrees. Such a line can be used to check maximum allowable slopes of pipelines for different types of materials with any particle size distribution. Figure 6 shows 150 mm and 250 mm test loops. These test loops can be used to operate auxiliary test loops of 200 mm and 300 mm diameters as shown in Figure 7. The largest test loop with a diameter of 500 mm is shown in Figure 8. This test loop is one of the largest controlled test loops in existence at the present time and was constructed for a project of Suncor

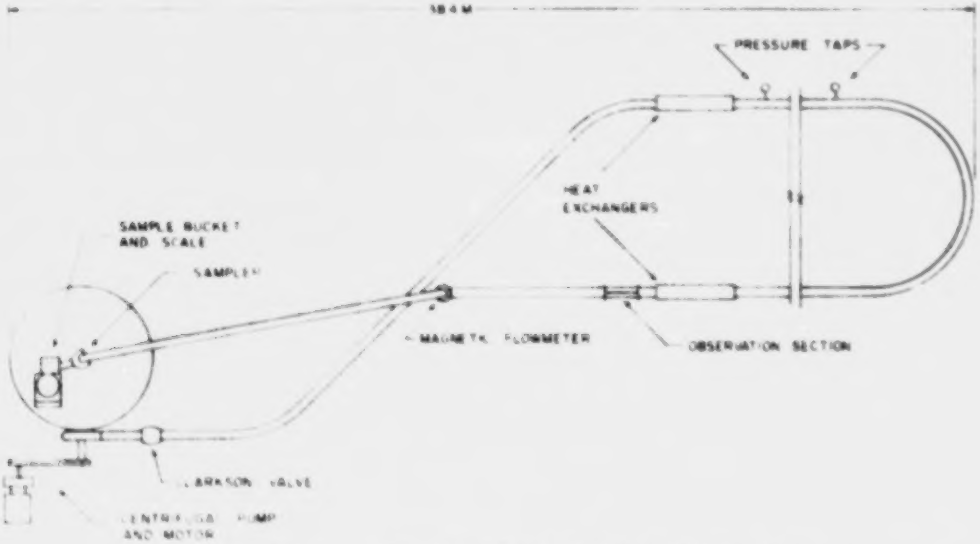

18.4 M
PRESSURE TAPS
HEAT EXCHANGERS
SAMPLE BUCKET AND SCALE
SAMPLER
MAGNETIC FLOWMETER
OBSERVATION SECTION
CLARKSON VALVE
CENTRIFUGAL PUMP AND MOTOR

Figure 4 100 mm closed pipeline loop

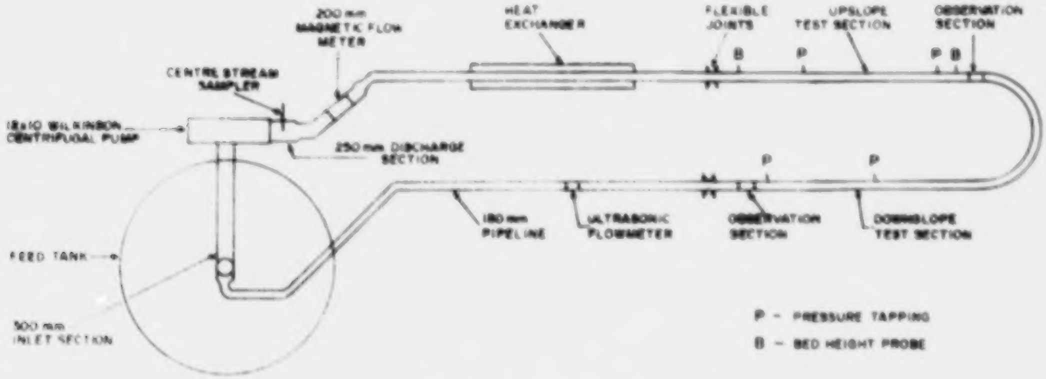

200 mm MAGNETIC FLOW METER
HEAT EXCHANGER
FLEXIBLE JOINTS
UPSLOPE TEST SECTION
OBSERVATION SECTION
CENTRE STREAM SAMPLER
18x10 WILKINSON CENTRIFUGAL PUMP
250 mm DISCHARGE SECTION
B
P
P
B
P
P
150 mm PIPELINE
ULTRASONIC FLOWMETER
OBSERVATION SECTION
DOWNSLOPE TEST SECTION
FEED TANK
500 mm INLET SECTION
P - PRESSURE TAPPING
B - BED HEIGHT PROBE

Figure 5 150 mm closed loop pipeline

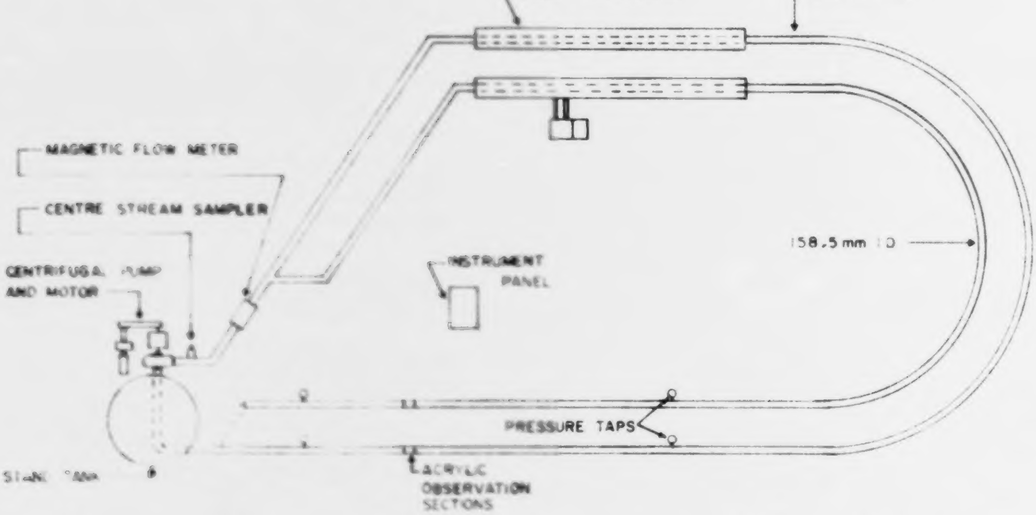

HEAT EXCHANGERS
263 mm ID
MAGNETIC FLOW METER
CENTRE STREAM SAMPLER
CENTRIFUGAL PUMP
AND MOTOR
INSTRUMENT
PANEL
158.5 mm ID
PRESSURE TAPS
STAND TANK
ACRYLIC
OBSERVATION
SECTIONS

Figure 6 150 mm and 250 mm closed loop slurry pipeline

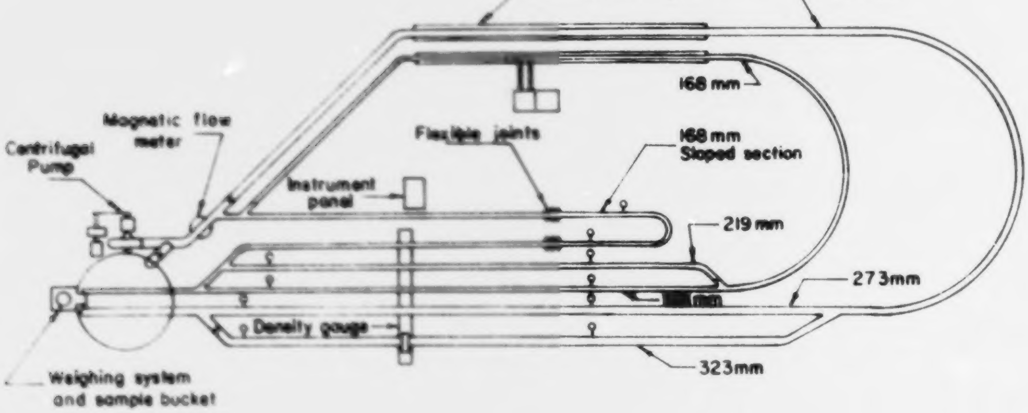

Heat exchangers
273mm
168 mm
Magnetic flow
meter
Centrifugal
Pump
Flexible joints
168mm
Sloped section
Instrument
panel
219 mm
273mm
Density gauge
323mm
Weighing system
and sample bucket

Figure 7 Slurry pipeline testing facilities

and Syncrude. Finally, Figure 9 shows a circuit used to determine the attrition which slurries undergo in passing through a pump and through different piping configurations.

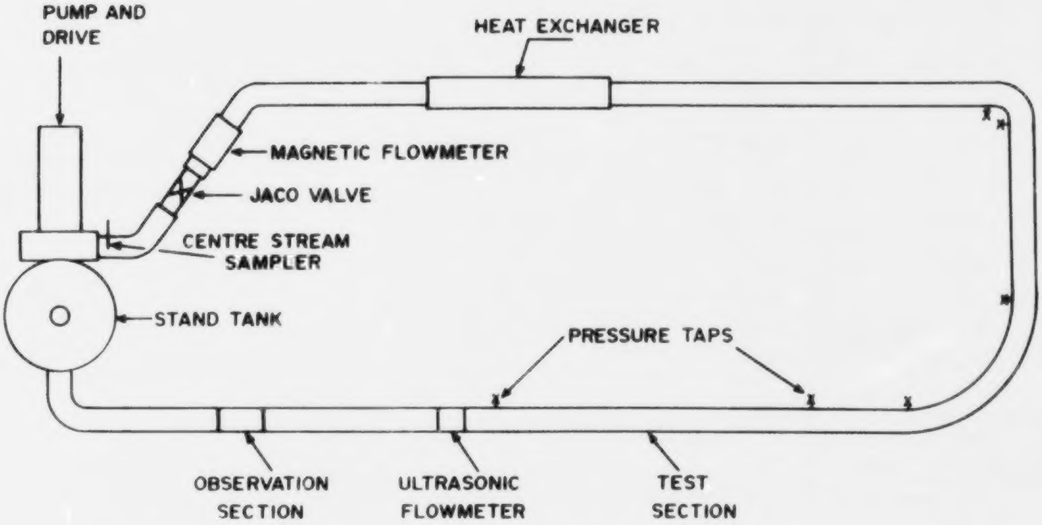

PUMP AND DRIVE
HEAT EXCHANGER
MAGNETIC FLOWMETER
JACO VALVE
CENTRE STREAM SAMPLER
STAND TANK
PRESSURE TAPS
OBSERVATION SECTION
ULTRASONIC FLOWMETER
TEST SECTION

Figure 8 500 mm pipeline loop

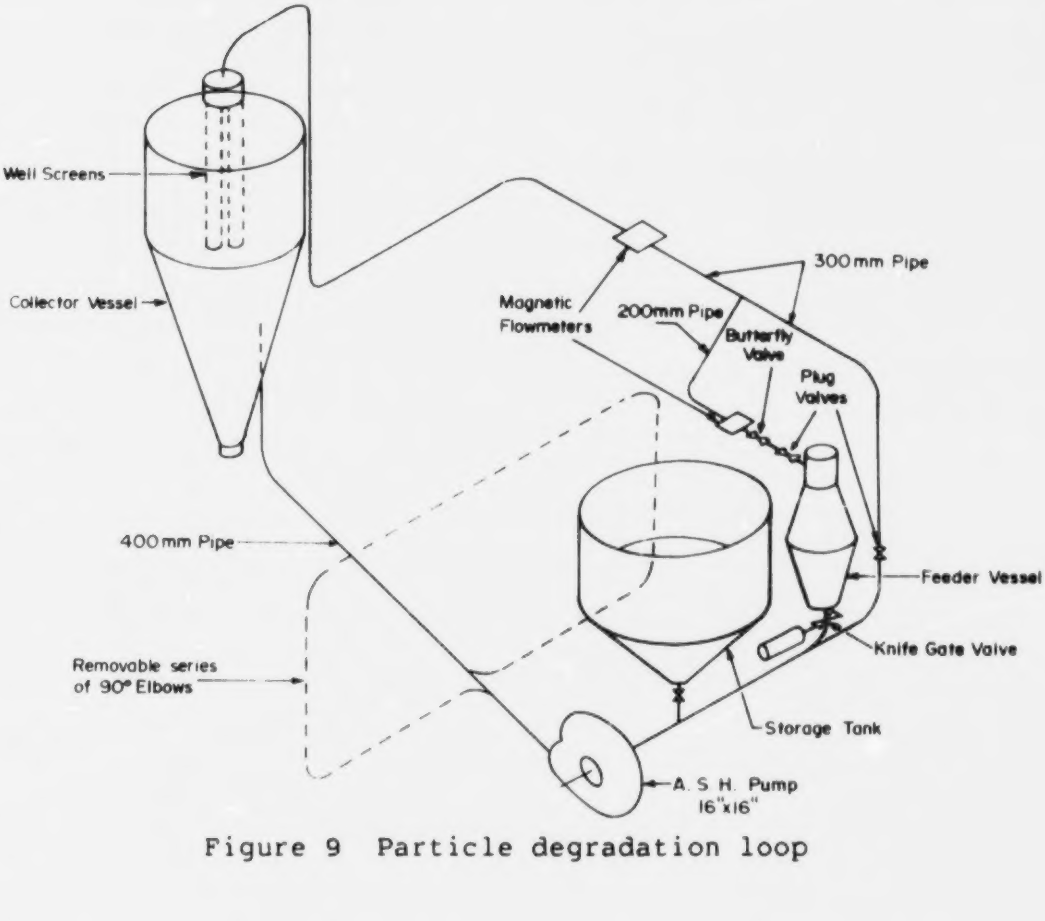

Well Screens
Collector Vessel
300 mm Pipe
Magnetic Flowmeters
200mm Pipe
Butterfly Valve
Plug Valves
400 mm Pipe
Feeder Vessel
Knife Gate Valve
Removable series of 90° Elbows
Storage Tank
A. S. H. Pump 16"x16"

Figure 9 Particle degradation loop

All pipeline test loops have temperature control. Slurry temperature can be varied from 0° to 60°C, even in the 500 mm line. System specifications and the quantities of solids required for testing in each system are summarized in Table 1.

TABLE 1
PIPELINE TEST LOOP SPECIFICATIONS

System Parameters	Special 50 mm loop	Standard 50 mm loop	50 mm heavy oil loop	100 mm loop	150 mm loop	150 mm loop with sloped section	250 mm loop	500 mm loop
Pump capacity, litres/sec	10	10	0.9	30	90	90	230	870
Power, kilowatts	20	13	10	190	190	190	190	220
Test section length, metres	5.49	5.49	5.79	12.17	23.79	10.67	28.95	22.86 or 45.72
Total line length, metres	27	30	26	73	100	80	130	140
Total system volume, metres								
open	--	0.62	--	2.3	20	20	24	--
closed	0.0674	0.0651	0.26	0.850	2.71	2.42	6.61	27.3
Weight of coal, 50% by weight slurry								
open loop	--	361 kg	--	1,340 kg	12 tonnes	12 tonnes	14 tonnes	--
closed loop	39.3 kg	37.9 kg	--	495 kg	1.58 tonnes	1.41 tonnes	3.85 tonnes	15.[illegible] tonnes

Procedures

Originally, work at the Centre involved relatively fine particle slurries. Tests were made with the pipeline test loops in open mode as shown in Figure 10. Known weights of solids and water were added to the system in sufficient quantities to fill the entire pipeline loop and the feed tank. Then, slurry was pumped from the bottom of the feed tank, around the loop, and back into the top of the feed tank at predetermined flowrates. Various measurements were made on the system at each flowrate. The feed tank was designed with a sufficiently large diameter to ensure very little change in head on the pump when slurry samples were removed from the system.

Work with large particle slurries began in 1976. Initial results revealed that particle segregation occurred in the feed tank. When slurries contained a range of particle sizes, the larger particles passed through the feed tank faster than the finer particles because of higher settling velocities. Thus, it became difficult to maintain fixed conditions in the pipeline loop. The problem was overcome by changing to closed loop mode as shown in Figure 10. Known quantities of water and solids were added to the system through the feed tank in sufficient quantities to fill the entire pipeline loop and to provide only about one metre of slurry in the cone at the bottom of the feed tank. After all solids had settled out of the cone into the pipeline, the valve at the discharge of the feed tank was closed. The slurry then was pumped around the test loop at predetermined flowrates, with the required measurements being made at each flowrate. Closed loop mode eliminates the segregation problem of open loop mode. All pipeline test loops except the 500 mm loop can be operated, if necessary, in either open or closed loop mode.

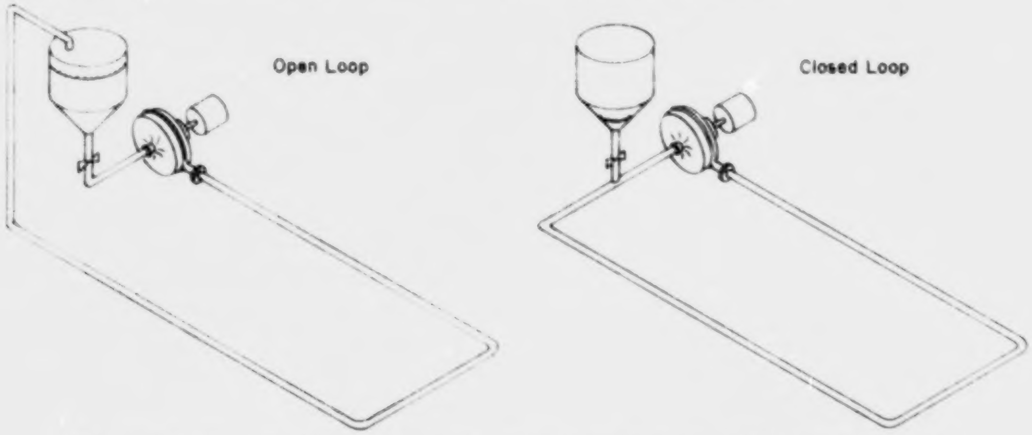


Figure 10 Definition of open and closed loop modes

A typical slurry test consists of filling the system as quickly as possible with the required solids concentration, setting the flowrate at the highest velocity to be tested, recording the required measurements, resetting the flowrate at a lower velocity, repeating the measurements, and continuing this step-by-step reduction of velocity until the solids begin to bed out on the bottom of the pipe. At this point in the test, either additional solids are added so that the process can be repeated at a higher solids concentration, or the system is emptied into a slurry disposal sump. To provide a hydraulic reference state, and to check the system's performance, water tests are made before and after each slurry test. These tests are identical to a slurry test but without any solids present in the pipeline. The results are checked carefully with previous water tests in the same pipeline loop to detect any differences. If significant differences occur, the causes are determined and, if necessary, the slurry test is repeated.

During a slurry test the following variables can be measured and recorded:

pressure drop over the test section of the loop,
average slurry flowrate,
deposit velocity,
slurry concentration,
slurry temperature,
solids concentration distribution in the vertical direction,
particle size distribution at various locations in the pipe cross-section,
pump torque,
pump rpm,
pump discharge pressure,
differential pressure across the pump.

Attrition tests have been carried out using a 16" x 16" ASH centrifugal pump and 400 mm diameter piping as illustrated in Figure 9. Originally installed in late 1980 for work with deep sea nodules, the equipment since has been used to study attrition of metallurgical coal and the effects of pipeline transportation upon the coking qualities of such coal. A typical test consists of filling the system with water, starting the pump, and adjusting flowrates through the feeder vessel and the main line to predetermined values. Then the butterfly valve on the branch line to the feeder vessel is closed and the pump stopped. Up to 500 kg of solids are added to the feeder vessel. The pump is restarted and hydraulic data are recorded for about 10 seconds with the branch line still closed. Then pneumatic actuators on the feeder knife gate valve and the branch line butterfly valve are triggered simultaneously. The valves open over a period of 1.7 seconds. The solids are discharged from the feeder, pass through the pump, and are gathered in the collector vessel. Although the solids pass through the pump in about 5 seconds, hydraulic data normally are recorded over a period of 35 seconds. The concentration of the solids in the slurry passing through the pump can be varied by changing the flowrates and the amount of solids placed in the feeder vessel. After the 35 second period, the pump is stopped and the solids settle in the collector tank. The water is drained off and the solids are removed for particle size determinations. In the case of coking quality studies, the entire charge of coal in the collector tank can be sent to the Western Regional Laboratory of EM&R at Edmonton for coking tests.

Instrumentation

Most of the hydraulic information is recorded by a data acquisition system which can process the data and print the results in graphical form.

Pressure or pressure drop over the length of test sections of pipe is measured with Viatran transducers. Slurry flowrate can be measured several ways, depending upon the test conditions. For open loop mode, the flowrate can be determined by full pipe discharge into a weigh tank with an accuracy of better than ±1%. Magnetic flowmeters are used for operator control. For closed loop mode, the flowrate can be determined by magnetic flowmeters, orifices, venture meters or ultrasonic flowmeters. Deposit velocities are determined by visual observation through clear sections in each pipeline loop. The clear sections are made of transparent plastic pipe.

Slurry concentration is determined by adding known weights of solids to known volumes of carrier fluid, by taking full pipe discharge samples, by taking centre stream samples immediately downstream of the pumps, or by gamma ray traverses over the vertical axis of the pipeline. Slurry temperature is measured by dial gauge for operator control and by temperature transducers for the data acquisition system. The concentration distribution of the solids over the vertical axis of the pipelines is determined normally by gamma ray traverses. Both solids concentration and particle size distribution can be determined in the 500 mm pipeline loop at any point in the pipe cross-section through the use of an isokinetic sampling mechanism. A one metre length of the 500 mm pipe can be rotated 360° about the pipeline axis while the line is operating. Mounted on this section is a sampling tube which is shaped like a pitot tube. This sampling tube can be positioned at any point over the cross-section of the pipe. Samplers are withdrawn through the tube at the same velocity which exists at the point of sampling.

Pump torque is measured by a Lebow torque sensor unit which uses a strain gauge and slip rings. Pump rpm is measured by magnetic pulse signal frequency. Pump discharge pressure and pressure differential across the pump are measured with pressure transducers.

A Neff System 620 high-speed analog data acquisition system is used. The Neff system converts analog signals (dc voltage) from flowmeters, pressure transducers, temperature transducers, etc. to digital signals. The digital signals are read by a Hewlett-Packard 9825 A computer. Coefficients obtained during instrument calibration are used to convert the digital signals to flowrate, pressure readings, temperature readings, etc.

During a normal hydraulic test, the slurry flowrate is set manually. The outputs from each instrument are then read 20 times per second for about one minute. The averages of the readings are printed out and the individual readings may be stored on cassette tapes for manipulation at a later time. The flowrate then is changed and the data gathering process is repeated.

A Hewlett-Packard 7245 A plotter-printer is used to present the results of the test in tabular or graphical form.

Associated Services

The Slurry Pipeline Development Centre has access to all the services of SRC, such as an analytical chemistry laboratory, a precision instrument shop, an electronics shop, a physics laboratory, a computer centre, and a large technical library with direct access to information centres around the world. Most importantly, the Centre has access to a general workshop with non-unionized tradesmen of all categories. These tradesmen are qualified to participate in the experimental programs as technologists.

Other associated facilities include a rheology laboratory at the University of Saskatchewan, a multi-purpose pilot plant and a Slowpoke nuclear reactor. The multi-purpose pilot plant has 870 m^2 of floor space containing crushing, grinding, classifying, and thickening equipment capable of handling 70 kg per hour of coal. The nuclear reactor is used for neutron activation analysis and can provide radioactive tracers.

Materials Tested

Initial work in the early 1960's was restricted to sands of various size distributions. The first, large scale work was done with potash and potash brines. Then sand and various mill tailings were used to investigate different flow regimes and types of pipe. During the three year contract for the CTC and TDA, considerable engineering data were obtained on the hydraulic transport of:

limestone,
iron ore concentrate,
potash,
thermal coal,
metallurgical coal,

and sand.

Since then, other materials investigated in the pipeline test loops have been:

common salt,
copper concentrates,
coal-in-oil,
coal-in-methanol,
various mine backfill materials,
tar sands,
tar sand tailings,
lignite,
zinc powders,
nickel concentrates,
deep sea manganese nodules.

Recently, interest has swung to slurries of large sized particles such as deep sea nodules and coarse coal. In response to this trend the Centre has been investigating pipeline transport of:

thermal coal with particles up to 50 mm in diameter,
rock with particles up to 50 mm in diameter,
nodules with diameters up to 100 mm in diameter.

Uses of the Hydraulic Data

The theory of fluid mechanics for slurry flow in pipes has not been developed yet to the stage where one can produce generalized equations capable of handling any type of slurry flowing at widely different velocities in different kinds of pipes. Much has to be done before such a stage is reached. Presently, several mathematical models, such as the Durand equations and the sliding bed model of Wilson, can be used for general guidance. However, pilot plant tests are required to complement these empirical or semi-empirical approaches available to help design engineers, to guide operators, or to give confidence to financial decision makers of multi-million dollar projects.

Large, long distance slurry pipelines must be operated under reasonably steady conditions to be economical. The combination of operating costs and capital costs have to be optimized over the life of the pipelines. Such a requirement does not allow wide fluctuations in throughput. Yet chemical and metallurgical plant personnel know that in-plant slurry lines and tailings disposal pipelines never operate under fixed conditions day in and day out. Processing variations, power outages, equipment failures, and operator misjudgements occur and impose wide fluctuations on such pipelines.

Therefore, the objective of the pipeline tests at the Centre is to provide information to cope with both types of pipeline conditions. Test conditions are varied widely to cover in-plant situations and to determine the optimum conditions. Pressure drop data (hence power requirements) are determined for wide ranges of slurry velocities and solids concentrations (flowrate and throughput) over as wide a range of pipe diameters as possible with the funds available under each contract. Deposit velocities also are determined over a range of pipe diameters. In conjunction with the semi-empirical equations, the data then can be used to determine the optimum solids concentration, slurry velocity and pressure gradient for a specific pipe diameter, or to predict the pressure gradient and deposit velocity in other sizes of pipes for different concentrations, velocities and particle size.

Limitations to the Centre concern attrition of the solids in the pipeline and erosion or corrosion of the pipelines. At present, attrition and erosion data are meaningful on a relative basis. For instance, the attrition a particular metallurgical coal undergoes during a pipeline loop test can be compared to that of another coal under the same test conditions. But the amount of attrition that each coal will undergo on passing through a 50 or 100 km pipeline cannot be predicted accurately at this time. Absolute erosion rates can be determined realistically only in an operating line. Small pipeline loop tests cannot reflect truly the conditions of such a line. Recirculation of the solids changes the abrasiveness of the solids and influences such factors as the amount of dissolved oxygen in the system. Short test spools and liners usually do not have the same quality as pipe produced in large quantities on production lines. Also, perfect alignment of spools and liners in the loop is difficult.

Currently the Centre is investigating the use of large diameter toroids to overcome these attrition and erosion difficulties. Toroids have been constructed for experimental studies in the USSR, the US, and in the UK. Properly designed tests in such apparatus potentially could provide realistic data for attrition and erosion without requiring excessive amounts of the solids concerned, nor long pipelines. If such equipment and tests could be developed at the Centre, a program could be initiated in Canada to provide data to predict separately the attrition a slurry undergoes in passing through the pipeline itself, the attrition of the slurry in passing through each centrifugal or positive displacement pump installed along a pipeline, and the erosion/corrosion rates in the pipeline.

Pilot Scale Capability of Solids - Pipeline Application

Reinhard Klose, Stahlwerke Peine, Salzgitter AG, Germany

Figure 1 shows a diagram of the pilot plant for the hydraulic transport of solid material belonging to Stahlwerke Peine-Salzgitter AG.

The plant comprises three basic sections:

- Section 1 Slurry preparation
- Section 2 Test circuits
- Section 3 Receiving

Slurry preparation

The preparation circuit includes two feeding bins for the solid material, beneath which a movable conveyor-type weigher deposits the test material onto a conveyor belt. This conveyor belt transports the solid material into the mixing tank. A screen at the end of the belt prevents oversized matter from entering the tank. A fresh-water pipe equipped with an inductive flowmeter also leads into the mixing tank. The conveyor-type weigher and the flowmeter enable the concentration of the mix in the tank to be set precisely.

The mixing tank can hold up to 125 m^3. This amount is sufficient to fill the three pipeline loops and the spiral-weld pipe shown in Figure 1. Furthermore, the DN 300 pipeline loop, including the pump sump, can be refilled from this amount. This ensures that the same material will be available for tests in the four pipelines with enough remaining for an additional test in the DN 300 pipeline, if this should prove necessary. This becomes even more important when we realize that the composition and condition of the suspension in all four pipelines must be the same when examining the effect of the pipe diameter on the hydraulic parameters.

In order to prevent the solid matter from settling on the floor of the tank and in order to homogenize the mix, the mixing tank is provided with a speed-controlled agitator. The agitator has two blades set at 90° to each other. In addition, four baffles are fitted to the walls to provide extra turbulence. Four discharge lines, arranged at different levels, lead from the mixing tank into a common suction line of a centrifugal pump which can pump the suspension back into the mixing tank. This mixing circuit or circulation loop is necessary in order to acquire information about the homogeneity of the mix. To this effect there is a radioactive density meter (γ-emitter) and an automatic sampler installed in the vertical pressure pipe of this circuit. The four stop cocks at the discharge nozzles of the tank are made up of three hand-operated slide valves for the discharge lines mounted on the side of the tank and one hydraulic slide valve, which can be set at any position, for the discharge line in the floor of the mixing tank. In this way it is possible to take a defined quantity from the required level within the tank. By setting the four valves selectively it is possible to investigate the various layers of concentration and particle size range which one could encounter in slurry tanks.

Test circuits

The test circuits of the plant for the hydraulic transportation of solids include a DN 200, DN 300 and two DN 400 pipelines. The DN 200 loop measures 233 m in length, the DN 300 loop 261 m, the DN 400 loop (seamless pipe) 289 m and the DN 400 spiral-weld pipe 112 m. The different lengths of each circuit are explained by the fact that the stretch of pipe used to measure the differential pressure must begin at a specific distance downstream of a bend, namely 130 times the diameter of the pipe. A series of tests has already been performed when it was shown that the effects due to turbulence caused by the elbow could no longer be measured at 130 x D downstream of the elbow.

All valves installed in the pipeline system are activated either hydraulically or electrically. The pilot plant can be operated either as an open system, i.e. via the pump sump, or as a closed system. If the plant is running as an open circuit, it is possible to direct all of the volume flow into a measuring tank for a certain amount of time.

In addition, samples can be taken from the circuits in order to determine the granulometric, rheological and other physical data of the suspension.

The DN 200 circuit of the pilot plant also has two further features. There is a 6 m long vertical section of pipe in the DN 200 pipeline. Also the 200 pipeline loop has been provided with a lifting device at the far end which allows the whole section of pipe to be raised to any angle up to 20°. The settling behaviour of the suspensions when the pipeline system is shut down and the whirling movement as the pipeline is restarted can be observed by means of glass inspection segments in the horizontal and inclined pipe sections.

A centrifugal pump with a 1,000 kW D.C. motor is used as the power unit for the pilot plant. The pump is regulated by thyristors. The pump has an infinitely variable speed range of 0 to 750 rpm and is able to pump 1600 m^3/h slurry.

The pump sump for the main line pump of the plant can hold 15 m^3. It is provided with a speed-controlled agitator and baffles as are all the other tanks. Two pipes measuring 200 and 350 m in diameter and which can be opened as required form the discharge line from the pump sump and consequently the suction line for the pump.

The total volume flow can be discharged into a measuring tank for a certain amount of time by means of a deflector installed on the delivery side ahead of the pump sump. The measuring tank rests on three pressure cells and has a capacity of 5 m^3.

Receiving section

The receiving section of the plant includes a tank with a capacity of 125 m^3. This tank is equipped with a speed-controlled agitator and baffles as are the other tanks. Another component of the receiving section is a 25 m^3 capacity water storage tank used to flush the pipeline. The water from the water storage tank and the water from the full pump sump is admitted into the pipelines via the centrifugal pump and forces the suspension into the receiving tank. The solids/liquid mix is flushed out of the plant by means of a water plug.

Representative large-scale samples can be taken as the mix is forced out of the pipelines. With this aim in mind, a deflector has been installed ahead of the receiving tank in the discharge line through which all of the volume flow can be diverted into a large-scale sampler. In this way, three large-scale samples of slurry measuring 1.5 m^3 each can be extracted for further examination. The rest of the suspension is fed into the receiving tank.

Test methods and procedure

One of the first aims of the tests was to simulate the hydro-mechanical stressing of coal suspensions in the laboratory. The slurry was stressed with the assistance of an agitator resistance tester. Analog comparisons between pipeline tests and agitator tests permitted the transfer factors to be determined. An in-process computer controlled rotating viscosimeter with a special pump apparatus provided information about the rheological behaviour of the suspensions. The pressure loss curves for coal/water mixes calculated from the flow curves, corresponded closely to the pressure loss curves actually measured in the pipeline. The deviation between measured and calculated values is around 5%. In order to record quasi-on-line, the change in the particle size distribution of the solid in the suspension, both during pipelining and also as a result of the stressing in the agitator resistance tester, an on-stream process for analyzing the size distribution by means of an image analysis system was developed.

It offers the possibility of carrying out a complete particle size analysis, for the range 1 micron - 3 mm within one hour. The particle size distribution is the main information, other information is also received, e.g. the structural factors in the individual particle size classifications. It should be pointed out that this system is also used for the fully-automatic analysis of the maceral compositions of polished coal specimens; with this process, 95 - 98% of the components of the coal are analyzed. Besides the image analysis system, the Coulter Counter, which covers the range <60 microns, is also used to determine the fines of the solids.

Slurry Pipeline Transport

The Salzgitter pilot plant to determine the hydraulic properties of solids/liquid suspensions is the centre of a research project being supported by the government of the Federal Republic of Germany. The in-process computer controlled plant includes all the components necessary to determine optimally and quickly the design parameters for solids pipelines. Slurry preparation (preparation of the suspension) is an integral part of this system as is the possibility of dewatering the solids/liquid suspensions.

The actual pilot plant comprises 3 sections:

- Preparation section - This plant system allows a pre-determined solids to liquid ratio to be set exactly. The mixing tank with agitator[5] and the circulating pump ensure that the mix is homogeneous. A density meter and the sampler for taking small samples guarantee that the homogeneity of the mix will be monitored closely.

- Testing section - The 3 pipe circuits have inside diameters of 200, 300 and 400 mm. Each pipe can be operated as an open or closed system. The main line pump[9], which is driven by a speed-controlled D.C. motor with a power rating of 1000 kW, ensures that a transport velocity of 6 m/s can be achieved even in the 400 mm diameter loop.

The lengths of the pipes in the individual loops vary between 233 and 289 m. These lengths are necessary in order to prevent turbulence at the pipe elbows from adulterating the measurements. The measurement values such as velocity, density, differential pressure and critical velocity are recorded in each pipeline by at least two different measuring systems. Temperature and absolute pressure are only measured once. Each pipe system has a sampler[7] for taking small representative slurry samples from the pipelines.

When operating the 3 pipe circuits as an open system, it is possible to direct the content of one pipeline section into the measuring tank[15] for a certain amount of time. The concentration and velocity values obtained in the measuring tank serve as calibration for the on-line measuring systems. The 200 mm pipeline circuit has two features. Firstly, this loop contains a 7 m long vertical section[10] in which the vertical flow behaviour of the suspension can be investigated, and secondly the final 12 m of the pipeline can be raised steadily to 20° so that investigations can be carried out into the settling and restart behaviour of suspension in inclined pipeline sections. An inhibitor tank[21] completes the pipe system.

- Disposal section - In this part of the plant, solids/liquid suspensions which have been transported through a pipeline over a simulated distance of several hundred kilometres can be collected, stored and processed. The distributor for large samples[18] ensures that representative amounts of slurry are available for further investigations such as dewatering, pelletizing, coking, etc.

The Salzgitter pilot plant has been dimensioned so that scale-up is not necessary for the majority of possible pipeline designs, i.e. a material can be investigated at this pilot plant in the diameter of pipe in which it will later be transported. Thus, this system results in the correct dimensioning of a pipeline. An on-line evaluation of the measurements ensures that nothing is overlooked. A special laboratory attached to the pilot plant also investigates all values which influence the hydraulic transportation behaviour such as flow behaviour of the suspension, particle size distribution of the solids, pH value, potential, conductivity, etc.

Mr. Klose gave a slide presentation on the facilities available for slurry research at Salzgitter in Germany.

He indicated current research is focused on dense coal slurries that are 70 to 80 per cent coal by weight. The aim is to find a feasible way to replace oil with coal. A total system will be required to accomplish this including burners, tankers, pipelines, etc. Mr. Klose indicated his company will be test-burning dense coal in a blast furnace during the next few months. Related questions which must be addressed are slurry pipeline transport up to several hundred kilometres, shiploading facilities, marine transport of coal slurry, and unloading facilities. These questions should be tackled during the next few years. Cooperation with Canadians on these issues would be desirable.
Mr. Klose indicated that Germans have a lot of experience in the burning of dense coal slurries.

Questions on Paper by Klose

Q: What is the total investment in the test facility?

A: It is 10 million dollars (50% from government, 50% from industry).

Q: Are there facilities to study erosion at the Saskatchewan Research Centre or at Salzgitter?

A: Not at Salzgitter. You cannot simulate this process in test loops, only in the laboratory.

A: We had four test loops at the Saskatchewan Research Centre to measure erosion, but there are problems measuring it in test loops, and the results were of limited usefulness.

A: Work is going on at the Energy, Mines and Resources Canada lab in Ottawa on corrosion - not on erosion.

Q: What kind of allowance in millimetres per year is made for erosion in pipelines?

A: There is no agreement on ways to measure pipeline wear. We need some long-term tests to be done on this. We have only past operating experience to go on. This operating experience is gathered under vastly differing conditions - not under the controlled conditions required to produce design specifications.

Q: Do any standards exist for erosion in pipelines?

A: No. But there are standards for corrosion. More research is required to understand the process.

A: Erosion is very important. It can require pipe replacement every three or four months. Tom Aude should be able to provide you with the design allowances currently in use.

Q: The imaging technique used to assess particle size was not originally developed for slurries. How useful is it really?

A: We developed a testing system for this at Salzgitter. It is not an optimal measuring system, but it does provide us with some information. The shape factor is important in the selling of material.

Q: How does the Saskatchewan Research Centre contract with industry for research?

A: We need to advertise our services to industry regularly to do this more effectively. We tried distributing a brochure, but it did not work very well. People leave and the new person is not aware of our facility. We also tried publishing papers, but there is only one journal geared to the mining industry. We need a regular publication. Most of our new clients hear about us by word-of-mouth.

Q: Who paid for the large bins at the research centre?

A: Fifty per cent of the cost was paid by the federal government and fifty per cent by the contracting company. However, the contractor usually pays for any new equipment.

Q: Will there be a change in your organization in 1983?

A: Yes. An internal reorganization of the whole research centre - not just the slurry pipeline section.

Gravel:

Canadian government policy on research funding is usually to pay for equipment in order to reduce the cost to industry of doing research. Grants are also made to companies doing research projects of general interest on the condition that the findings are made public. However, there is a general shortage of funds available to sponsor research in Canada.

Q: Who pays the Saskatchewan Research Centre staff when there are no industry contracts?

A: People have to be laid off. We try to avoid losing our key people; we switch them on to fundamental work. We are trying to work out a way to cope with this problem, but it is very difficult.

Young: Selection and Design of Slurry Pumps

Douglas L. Young, Ingersoll-Rand Canada Inc., Montreal

The following is an interim report on new mainline pump for coal slurry which is being developed in Canada by Ingersoll-Rand. The company builds a variety of pumps for natural gas pipelines and ore slurries. It was also involved in experiments on pumping woodchips. In addition, the company produces solids-liquids separation equipment for pulp mills.

The operating experience of the Black Mesa pipeline in the United States was studied to determine slurry pipe and pumping requirements. The company wanted to select and design a new slurry pump to meet the needs of the slurry pipeline industry. The study began with an investigation of consumer needs (i.e. large throughput, moderate pressure, etc.) which after careful evaluation led to the conclusion that the most cost-effective pump for this application was the double active (positive displacement) piston pump, centrifugal pumps being ruled out as too inefficient, and diaphragm pumps being eliminated because they are too prone to fatigue. He described the general features of the pump design at the power end (i.e., overhead accessibility, no interval gears, etc.) and at the fluid end. He indicated that the design is approached in two stages; the first stage extrapolates the design from state-of-the-art knowledge, the second stage the higher speed, higher capacity operations.

A full-scale, full-power test facility, the new Ingersol Rand slurry pump facility, is operating at Cambridge, Ontario. A prototype pump is currently being built, with tests expected to get underway in the next few weeks. The Cambridge facility is capable of testing complete pumps and components. We are not using coal slurry at Cambridge because it breaks down too quickly under continuous test conditions. A sand slurry is being used for test purposes, even though it is difficult to relate the sand slurry wear results to slurry wear results. The concentration is 50 per cent sand by weight.

A sophisticated data logging and monitoring system has been installed in the test facility. The system utilizes minicomputers, which update readings every 20 seconds.

A funding grant was received from the Canadian government for this $12 million research program. The grant covers 40 per cent of direct costs up to a certain ceiling. The company is funding the equipment consumed in the program. Canadian tax credits for eligible research expenditures are worth as much to the company as the direct grant.

Questions on Paper by Young

Q: Would Ingersoll-Rand cooperate with others to investigate related issues such as pipe erosion?

A: We haven't thought much about this as yet. We will be testing for fatigue during the first two-and-a-half months, but after this is completed, we might be willing to accept contract research. We would not be willing to work with a competing pump manufacturer.

Q: Is your company optimistic that Canadian as well as American coal slurry pipelines will be built?

A: We are confident the business will develop. We are looking at markets for coal and ore slurry pipelines all over the world, not just in North America. The second phase of our research program will look at pump design for dense and coarse coal slurries. If Canadian industry does not act to meet the needs of this potential industry, it will be too late if and when the market does develop. Interest is also shown in Europe, the USSR and Australia. The pumps have the potential for pumping ore.

Q: When will the first pump be available for sale?

A: Hopefully by the middle of 1983, in time for the ETSI startup.

Q: Why don't you want to use the flush cycle to avoid dilution of the slurry?

A: Because of the technical limitations of pumps due to the required lubrication.

Q: (To Young)
How many people do you have on staff to analyze the data generated by your Cambridge facility?

A: There is a problem getting enough skilled people. Ingersoll-Rand has four or five professionals and some technicians. We also have access to consultants at our company's central research facility at Princeton. We decided to go the project rather than the institutional research route. We will go outside the company for extra help if we need it.

Q: Has your data gathering system at Cambridge been designed for a specific analysis system in order to minimize the amount of analysis required?

A: Yes. Ninety per cent of the data generated will not be of any interest unless problems develop.

Three years ago, when pumps had to be selected for a 27 kilometre pipeline designed to transport 2.3 million tonnes of iron ore slurry in the U.S.S.R., the pump tests were not very encouraging. However, since then there have been many improvements in the design of slurry pumps.

Two types of pumps were tested: plunger pumps and reciprocating diaphragm pumps. Mr. Stephan summarized the test results.

Criteria for the Selection of Slurry Pumps

Dipl. Ing. Friedhelm Stephan, Salzgitter Industriebau GmbH,
Salzgitter, F. R. Germany

A few years ago we were faced with the necessity of selecting the types of pumps to be used for the construction of a slurry pipeline designed to transport 2.3 million t/a of iron ore concentrate. According to the project a maximum of 430 m^3/h of slurry at a maximum pressure of 75 Bars had to be pumped.

After checking all the possibilities, the field was finally narrowed down to two types of pumps, namely plunger pumps and reciprocating diaphragm pumps. The choice was made in favour of the reciprocating diaphragm pumps on the basis of the following criteria: The pipeline pumps which had so far not been used for long-distance slurry transport are slow-running reciprocating diaphragm pumps. The diaphragms of these pumps are designed as preformed, wear-resistant rubber diaphragms and are only stressed by bending.

The problem of maintaining stable conditions for the hydraulic fluid when admitting the slurry to the rubber diaphragms has been successfully solved by means of inlet and outlet valves. This system together with the related displays via control lamps shows the operator exactly how the pump is functioning. This system has proved itself in the pumping of oxygen converter dust and bauxite slurries, whereby 6 pumps have been used uninterruptedly for several years to pump oxygen converter dust slurries with 600 - 800 g of iron per litre and a maximum particle size of 3 mm. During this period diaphragms had to be changed only twice because welding electrodes had been pumped with the slurry, which resulted in some damage being caused.

Pumps of about the same size as those used in our project had been working with good results for a longer time in the aluminium industry at the Vereinigte Aluminium Werke in Stade, Germany. The long service life of the rubber diaphragms can be attributed to their good design and to the above-mentioned regulation of the hydraulic fluid which otherwise works completely free of maintenance. Even if a rubber diaphragm should fracture, there will be no subsequent damage to the sealing elements of the pump because the piston for the hydraulic fluid and the cylinder bushing are of a slurry-resistant design and capable of transporting abrasive materials for many hours. In the event of a fracture occurring at the diaphragm, control lamps will inform the pump operator of the exact defect. This signal shows directly the status of the pump, i.e. whether a diaphragm has fractured or whether hydraulic fluid is leaking at the piston.

The long service life of the pump's wearing parts can be attributed to the low number of strokes of the pump and also to the particular experience and the development work performed by the suppliers. The reciprocating diaphragm pump operates at about 43.5 strokes per minute. This low number of strokes is emphasized even more in comparison with the plunger pumps with sealing agents which, due to the high number of strokes of more than 100 per minute, neither achieve the same service life for the valves nor demonstrate a good service life for the plunger. The pump valves of the reciprocating diaphragm pump have proved themselves exceptionally well in practice and allow a service life of about 1,500 hours and more. By changing the valve plates at the appropriate time it is possible to increase considerably the service life of the valve seat and valve cone. For example, the valve plates are changed after 1,500 service hours which increases the life of valve seat and cone to over 3,000 hours.

The reciprocating diaphragm pump provided for this project in the form of a double assembly is equipped with a total of 8 suction valves and 8 compression valves; this gives a total of 16 valves against the plunger pump with 14 suction and 14 compression valves (as double valves), i.e. 16 valves altogether compared with 28 valves for the same discharge capacity.

The arrangement of 28 valves in the plunger pump contradicts in principle the requirement within modern engineering for larger machines. On the one hand, larger pumping units are being built for reasons of rationalization, but it is by no means justified in this case to have more valves, thereby increasing the probability of breakdowns.

Plunger pumps with direct admission were originally built for non-abrasive substances. Only with the introduction of sealing agents to protect packing and plunger passageways were these pumps used for abrasive substances. Besides the high number of revolutions of the plunger pump (over 100 strokes per minute) and the resulting greater wear on valves, plunger and seals (high wearing costs) in comparison with a slow-running reciprocating diaphragm pump with about 43.5 strokes per minute, the main criterion for a reliable slurry pump lies in separating the mechanical parts such as cylinder bushing and piston from the abrasive product to be conveyed.

With the reciprocating diaphragm pump we can view the separation between the abrasive slurry and the hydraulic fluid by the diaphragm as a mechanical separation, in contrast to the plunger pump where we speak of a hydrostatic separation which, in the light of experience, must be viewed as unstable. According to experience (oxygen converter dust and bauxite slurry pumping), the expected service life for a rubber diaphragm in a reciprocating diaphragm pump amounts to about 4,000 hours and more.

Furthermore, a particular feature of the reciprocating diaphragm pump is the rapid opening and closing of the valve and cylinder housings by means of hydraulic pretensioning devices. The bolts are readily and uniformly tightened to a certain degree. Hydraulic forcing devices are provided for the changing of valve seats and hydraulic fluid pistons.

Special attention should be paid to the above-mentioned devices because they bring great advantages as regards maintenance and increase considerably the operating reliability due to the even stressing of the tightened bolts. The above-mentioned hydraulic devices enable a rapid and safe changing of wearing parts without straining the service personnel. In addition, these design features reduce repairs and maintenance to a minimum.

We can state without fear of contradiction that maintaining a plunger pump with sealing agents makes greater demands on the operating and maintenance personnel because the above-mentioned hydraulic devices cannot be included in plunger pumps.

It should be generally mentioned that when using pumps for abrasive products they should be particularly well accessible and should allow the wearing parts to be changed quickly.

With a reciprocating diaphragm pump, the problem of possible over-pressure resulting from the pipeline is solved by means of accumulators located in the hydraulic fuild section of the pump. These accumulators are provided with a gas inlet pressure equal to the maximum design pressure of the pump. If this design pressure is exceeded in an undue manner by pressure surges or similar, then the valves or shock absorbers on the delivery side of the pump will take up this greater pressure.

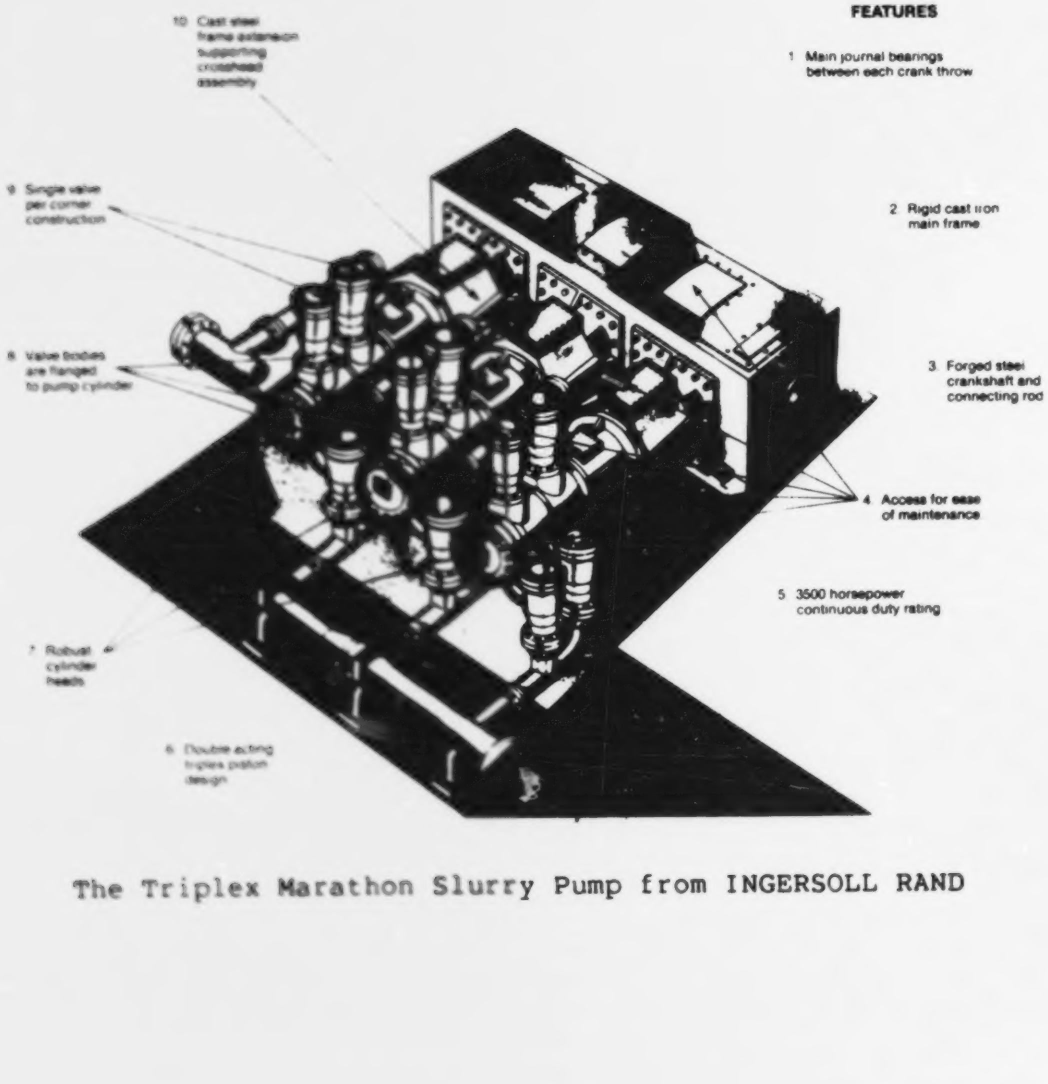
The design of the pump means that it is not in a position to overcome this greater counter-pressure. This pressure is directed into the accumulators in the hydraulic fluid section. This means that the drive motor merely has to overcome the bearing friction and is thus idling. A comparable plunger pump operating under the above-mentioned conditions would have to be either switched off immediately or the slurry would have to be circulated via a safety valve. It should be noted that these safety valves would have to be operational at all times and, if used, would certainly be damaged or destroyed.

Switching off the drive motor is just as less advantageous since, if it is switched off too often, problems will arise when restarting the motor. A pressure control device, which is padded in a fail-safe manner with nitrogen from the central pressure shock absorber, serves as a further safety measure for the reciprocating diaphragm pump. This pressure control device gives a signal to the operator in the event of overpressure.

One advantage of the reciprocating diaphragm pump over the plunger pump which must be mentioned is the fact that all bearings in the drive unit and the bearings for the connecting rod and crosshead pin are designed as roller bearings. These bearings are built to last for 40,000 operating hours. The well-known plunger pumps, however, are equipped with friction bearings.

Comparative Summary

Reciprocating diaphragm pump	Plunger pump
- slow-running	- fast-running
- mechanical separation of moving parts between slurry and fluid section by diaphragms	- hydrostatic separation between slurry and plunger, plunger passages and stuffing box
- all bearings designed as roller bearings including connecting rod and crosshead pin bearings	- all bearings in the pump designed as friction bearings
- a total of 16 valves, quick and simple changing of valves etc. due to good accessibility	- a total of 28 valves
- hydraulic auxiliary tools for changing wearing parts quickly, that means uniform pretensioning of most bolts	- bolts must be tightened immediately by hand with the aid of machine tools, that means uneven pretensioning of individual bolts
- diaphragm shock absorbers as safety elements against overpressure arising in the hydraulic fluid section	- pressure relief valve or motor shut-down


FEATURES
1 Main journal bearings between each crank throw
2 Rigid cast iron main frame
3 Forged steel crankshaft and connecting rod
4 Access for ease of maintenance
5 3500 horsepower continuous duty rating
6 Double acting triplex piston design
7 Robust cylinder heads
8 Valve bodies are flanged to pump cylinder
9 Single valve per corner construction
10 Cast steel frame extension supporting crosshead assembly

The Triplex Marathon Slurry Pump from INGERSOLL RAND

Questions on Paper by Stephan

Q: Would you recommend the reciprocating diaphragm pump for slurry pumping?

A: Yes. We are looking for ways to pump coarser slurries.

Q: Were these results for your company?

A: No. We are an engineering company - not a manufacturer. We are commenting as pump users; our objective is unbiased.

Q: Did you examine the possibility of energy recovery?

A: No, but the possibility existed that it could be done and the heat used to heat the plant.

Comment: The use of an energy recovery fluid was suggested.

Q: How many people would you have on hand to analyze the test data?

A: Four to five professionals plus access to additional highly qualified help from Princeton.

September 28, 1982
AFTERNOON SESSION

Stephan: .Problems in Separation of Solids from Liquids

Problems in Separation of Solids from Liquids

Dipl.-Ing. Friedhelm Stephan, Salzgitter Industriebau GmbH,
Salzgitter, F. R. Germany

The dewatering of solids after hydraulic pipeline transportation is - no doubt - one of the most important factors in the whole chain of materials handling. While in one of the two major branches of pipeline application, the transportation of iron ore concentrates, the dewatering of such concentrators with size distributions suitable for optimum hydraulic transportation can be considered as more or less solved, the dewatering of coal in the other big field of pipeline transportation creates considerable problems.

This is according to our understanding one of the main reasons, especially in the coal exporting countries, why no further pipeline projects could be realized so far, except those in the U.S.

What is the background of this appearance? Now, you all know very well, that the hydraulic behaviour of a slurry will be improved, the finer the grind can be achieved in the concentrator or slurry preparation plant. However, this finer grind is not in the interest of the dewatering operation, where the high portion of extremely fines causes difficulties to get rid of the surface moisture.

In Fig. 1 the coal size distribution curves of the Ohio pipeline, of Black Mesa, and of a tested coal after simulated long distance pipeline transport in our testing facilities are shown.

You may recall that Black Mesa Pipeline Inc. started operation with a coarser coal size consist. Every effort was done to optimize the pipeline operation without taking enough care for the needs in the Mohave power generating plant, where the dewatering plant had to cope with the higher fines. But the pipeline company and the power generator including dewatering belong to different companies, so that finally the dewatering people could not but try to make the best of it. Thus the pipeline operation is now being controlled on the fine fraction minus 44 micron (-325 mesh) at approx. 19%.

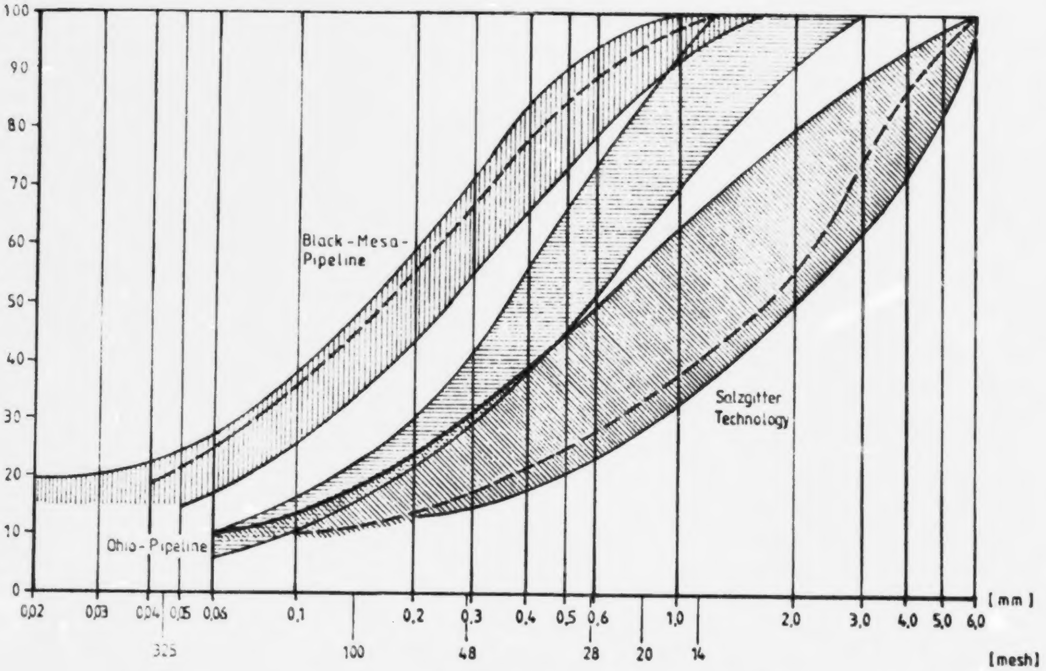


Figure 1 Grain Size Distribution of Coal from Different Pipelines

Fig. 2 shows the flow in the dewatering plant at Mohave. The slurry is heated up before being fed to screw centrifuges. The effluent containing considerable amounts of coal fines is collected in clariflocculators, and the underflow from this thickener is directly incinerated in the boilers. However, this incineration is not continuously possible, especially when the generators are operated under low-load conditions. In this case the underflow is led to large settling ponds, where the arid climate and the all-day shining run take care of the coal dewatering by evaporating.

The dewatered coal after the centrifuge still has a remaining moisture content of about 20-25%, which is only good enough for further processing in a power plant, i.e. one cannot think of shipping such coal overseas for export.

The envisaged consumers of coal from the planned ETSI-Pipeline do not have the same conditions like at Mohave. Therefore, a comprehensive testing program was carried out in order to solve the problem of dewatering the whole size consist. For this purpose, after laboratory and pilot plant tests, a large pilot plant with full scale equipment and a throughput capacity of abt. 50 tph was erected at the White Bluff Power Plant near Little Rock in Arkansas.

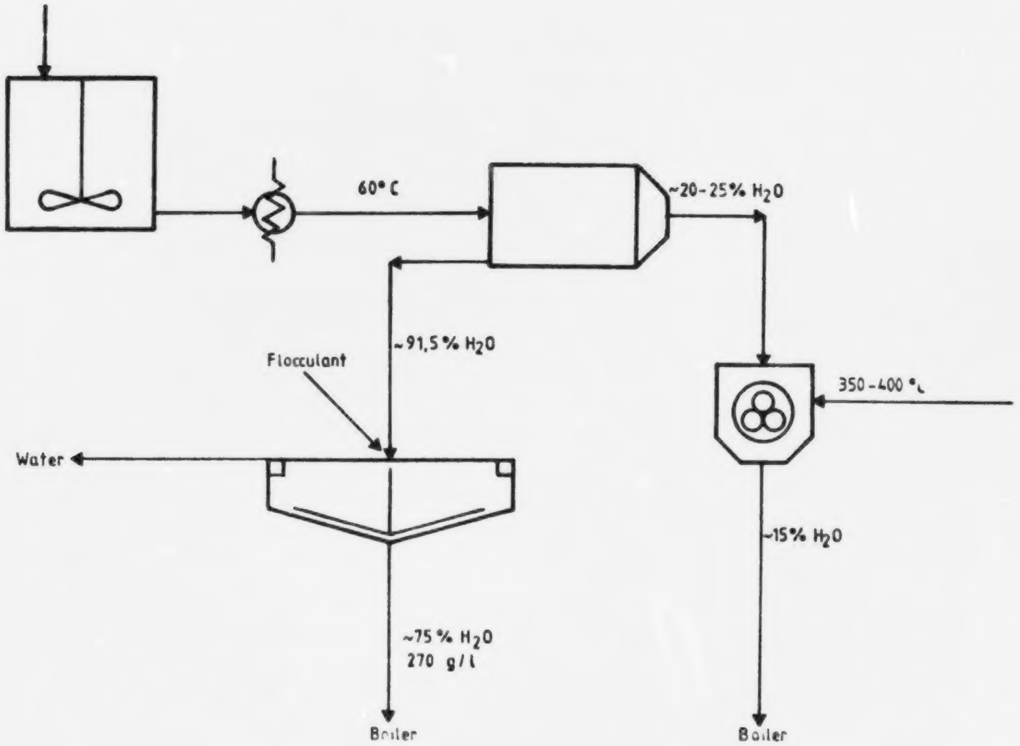


Figure 2 Mohave Power Station, USA
Process Flowsheet Dewatering Grain Size 0-1,2 mm

The objectives of ETSI's Coal Evaluation Plant (CEP) were amongst other aims mainly the dewatering of the coal from the Powder River Basin, which was ground to the same size consist like for the Black Mesa coal slurry pipeline, because this was thought to be a proven and successful technology.

Therefore, after having found out the optimum cage mill and rod mill circuit to reach this goal, the further research work had to

- demonstrate that the full scale screen bowl centrifuge and vibrating bed dryer could reproduce the results previously obtained in a 4 tph pilot plant,
- test the solid bowl centrifuge and alternate filtration-type equipment to determine the most effective approach to deal with the effluent from the screen bowl centrifuge,

- test and select types and dosages of flocculants and other chemicals needed in the various steps of the dewatering process,

- demonstrate that the dewatering circuit could be closed, i.e., that no fines were rejected.

This was a great task, and we must admit that test work was performed with care and diligence. The flowsheet of the dewatering process of CEP is shown in Fig. 3. The significant result is that in order to reach a final product below 10% moisture, thermal drying has to be included in the process. In the first step the slurry is heated up to abt. 190°F before feeding the screen bowl centrifuge. In the course of the research work it could be found out that the material from screen drainage is best used together with the effluent and the underflow from the thickener in the secondary dewatering instead of recycling.

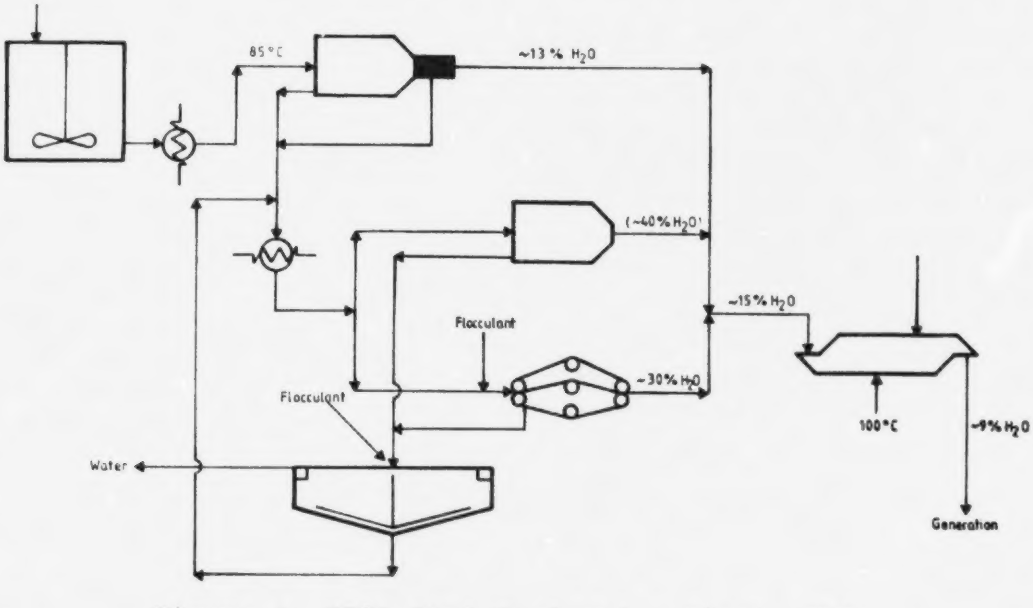


Figure 3 ETSI Coal Evaluation Plant, USA
Process Flowsheet Dewatering Pilot Plant Grain size 0-1,2 mm

This secondary dewatering was first also performed by a solid bowl centrifuge with a remaining moisture content of abt. 40%. This content could be reduced to abt. 30% after the solid bowl centrifuge was replaced by a continuous belt press filter. It is reported that the belt press filter produced a cake of about 50% moisture with effluent and thickener underflow only, and this could be improved to about 30% moisture when the screen drainage was combined with the fines, i.e. the size consist of the filter feed was considerably broadened.

The cakes of the primary centrifuge and the secondary belt press filter are jointly fed to the vibrating bed dryer where the moisture is reduced from abt. 20% to minus 10%. It has to be noted also that for clarification of the water flocculants have to be added; so together with the heat input the dewatering process will be in fact expensive, although no detailed figures have been given until now.

There is no doubt that technically a solution has been found to meet the requirements for dewatering such a coal with a size consist given by the pre-conditions for the design of the pipeline technology. It is astonishing, however, that this technology, which was completely taken over from Black Mesa experience, was now given firmly as basis for all consequent research work as the non-plus-ultra.

We must state that for the dewatering of such fine coal no other technology or better equipment than selected by ETSI's CEP can be proposed. We don't have any better recipe for this case. In Europe, quite a lot of research work is done on improvement of centrifuges, vacuum filters, press filters, etc., because the concentrator plants of underground mines have to cope with an increasing amount of fines due to higher grades of mechanization for the mining methods. So, for example, better results of remaining moisture in the cake of coal fines can be obtained by enhousing disk or drum filters and using pressure instead of vacuum, which is limited in the suction gauge. Other novelties are belt press filters as mentioned under secondary dewatering in ETSI's CEP, and vacuum belt filters.

Fig. 4 shows the results of dewatering different coal flotation concentrates on belt press filters.

Fig. 5 contains in the curves the dependency of the moisture content of the filter cake and the filter capacity form the amount of fines below 0,063 mm (-250 mesh), when using a vacuum belt filter. The filter was tested in a German Coal Washery over longer periods and under different conditions. From numereous samples taken over 3 weeks the mean remaining moisture content from a fine coal with an average grain size portion of 40% below 0,063 mm (-250 mesh) resulted in 20,1%.

		Plant in West-Germany Flotation concentrate	Plant in USA Flotation concentrate	Plant in West Germany Flotation concentrate from wash water flotation
Grain size				
<63 μm (-250 mesh)	%	55	50	80
<32 μm (-400 mesh)	%	30	25	50
Ash	%	10	5	7-8
Inlet consistency	g/l	235	230	180-200
Dry content with vacuum predewatering	%	83-84	84	-
Dry content without predewatering, with flocculent added	%	-	-	78-80
Output	t_{wf}/h	10-12	10-12	8-10

Figure 4 Results of various investigations on dewatering of flotation concentrate using the wire belt press

Many authors in their papers presented recently on the occasion of slurry conferences have pointed out that every effort must be done not only to optimize the hydraulic transportation but also to find the best solution for the whole chain, i.e. starting from the winning of the crude material into the demands at the final users end. Especially the given possibilities for overseas shipment of bulk material in case of export must be considered in detail.

For this reason, Salzgitter together with the German Ministry of R&D have developed a technology which permits transporting coal in the size range 6 x 0 mm after careful comminution of coal and slurry preparation. The upper grain size of 6 mm is limited only by the preconditions of the pump manufacturers who are not in a position to guarantee larger openings at their valves.

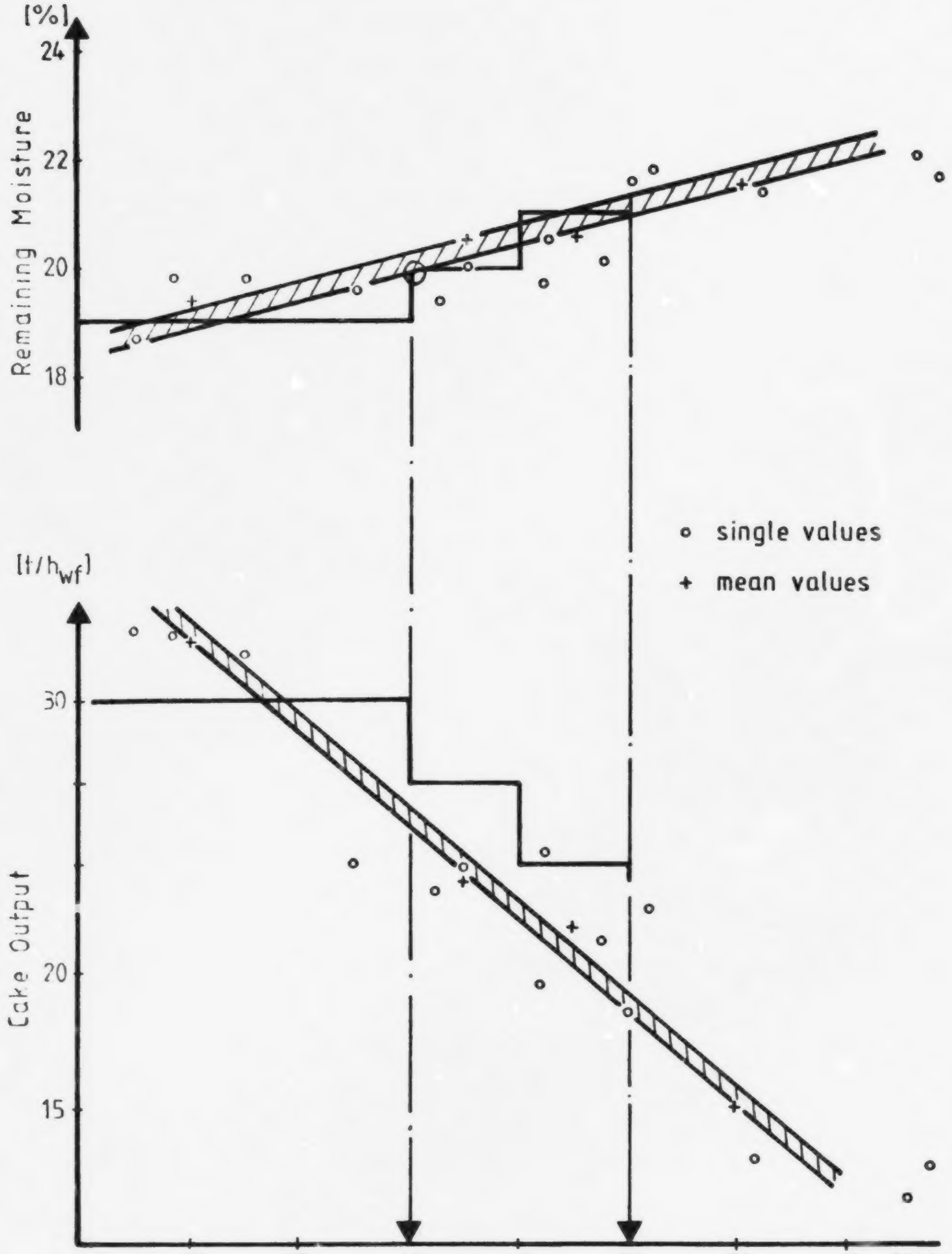


Figure 5 Results of long term dewatering tests with vacuum belt filter on a German Coal Mine

The dewatering of the piped coal in this size range is much easier and can be performed according to the flow sheet in Fig. 6. A split up of the whole fraction into 6 - 1 mm and 1 - 0 mm will be made by screening. Then the different flows are dewatered separately, the coarse material in centrifuges, for example in tumbling or pushing centrifuges as shown in principle in Fig. 7 and 8.

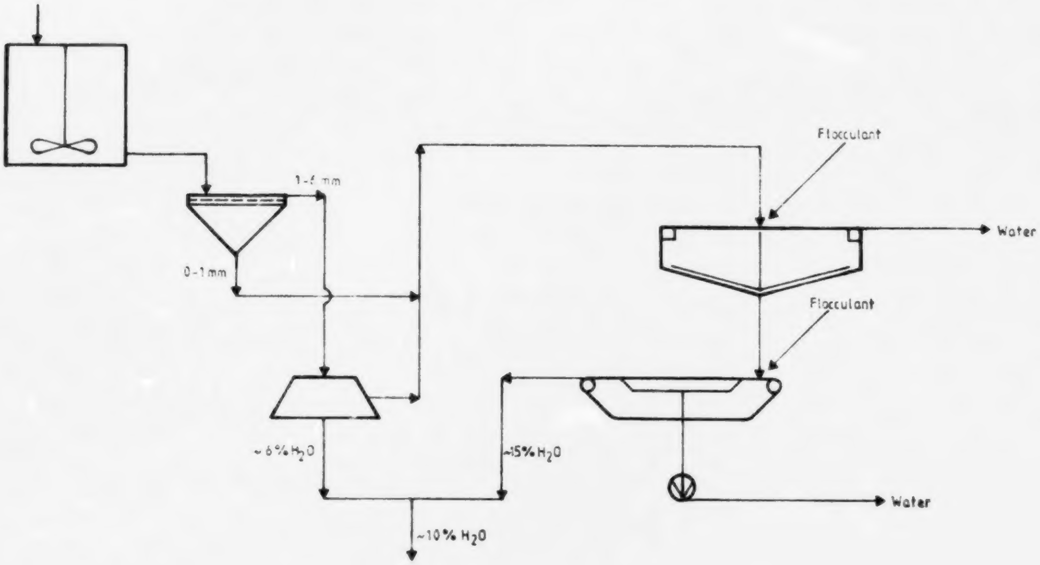


Figure 6 Salzgitter Technology
Process Flowsheet Dewatering Grain size 0-6 mm

The fine fraction can be dewatered on vacuum belt filters (see Fig. 9) in the way as explained above; however, due to the considerable less portion of fines below 0,063 mm (-250 mesh), the effect of dewatering will be increased to such extent that a product with 14 - 16% water will be reached, so that the total remaining moisture of the combined coarse and fine fractions will not exceed 10%.

This material can be further shipped and used for any purpose at the final destination, i.e. can be transported by conventional ocean carriers, and the coal can be also used in coking plants for metallurgical purpose.

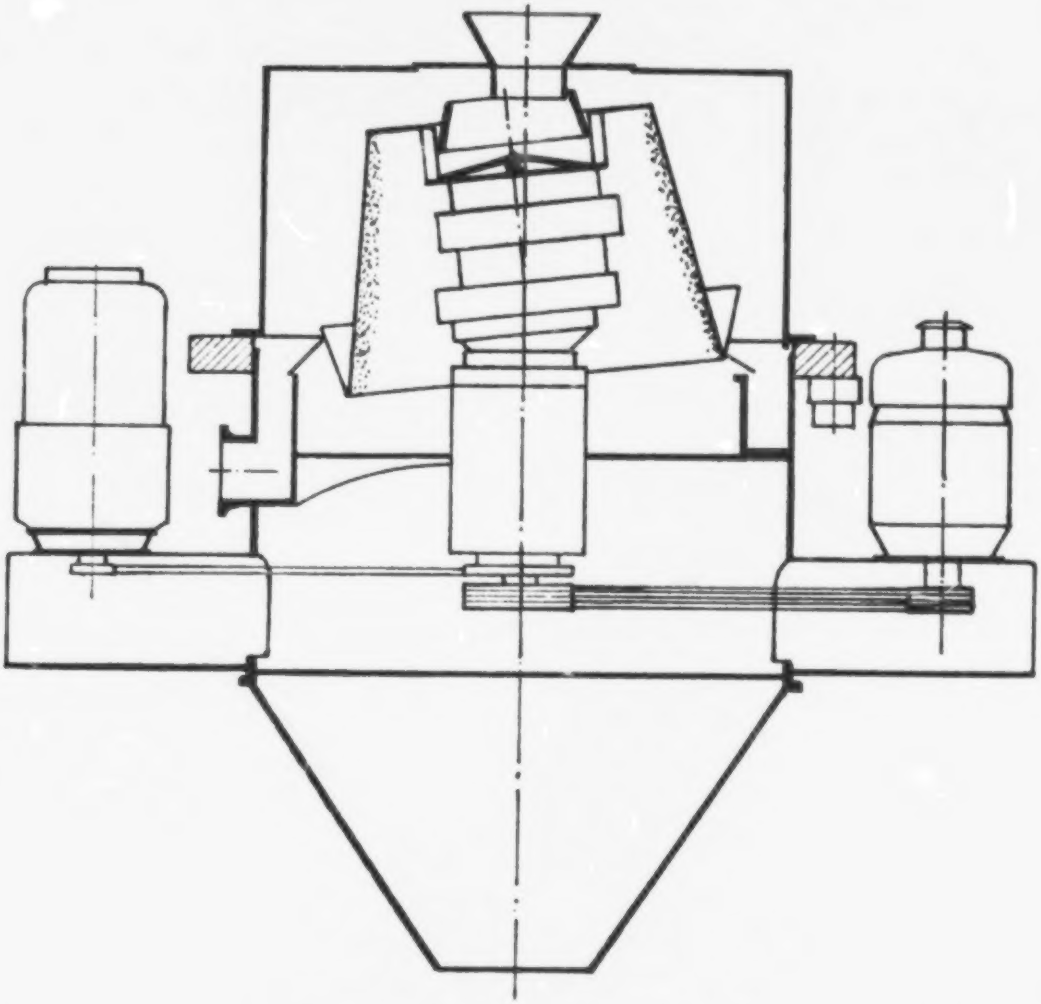


Figure 7 Tumbler Centrifuge

Although the pipeline transportation for a coal of such size consist is not really optimized, it must be clearly stated, that the rheological behaviour is not decreased as much as one would believe, and the pressure losses and energy requirements are still in the range of economic operation, i.e. the slurry transportation velocity will vary between 1.6 and 2.2 m/s.

By improving the dewatering on this case, this minor result from pipeline operation can be accepted, as the whole system will be improved considerably.

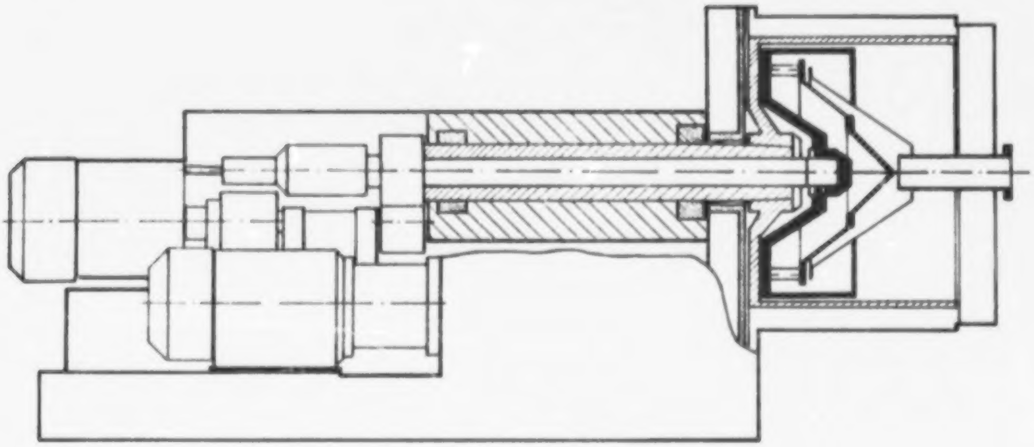


Figure 8 Pusher Centrifuge

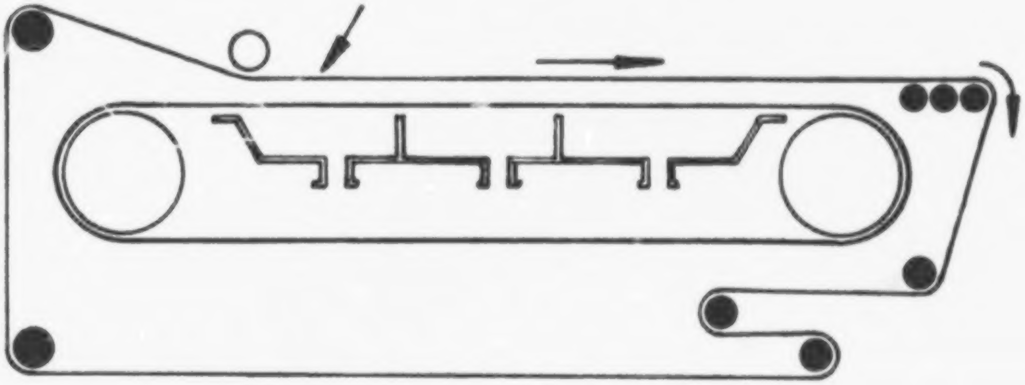


Figure 9 Vacuum Belt Filter

Questions on Paper by Stephan

Q: How much -63 micron coal is in the proposed slurry consist?

A: Between 10 and 15 per cent.

Prediction of Size Degradation of Coarse Coal During Slurry Pipeline Transportation

M.W. Mikhail and R.J. Mikula, Western Research Laboratory, Energy, Mines and Resources Canada, and W.H.W. Husband, Saskatchewan Research Council

During the transportation of friable coals via slurry pipelines, some degradation inevitably occurs. The fine material produced increases the cost of dewatering and may adversely affect the quality of metallurgical coals. Evidence is presented that permits prediction of the relative size degradation that occurs during slurry pipeline transportation of various coals.

Data from a standardized procedure for measuring the rate of methane desorption from a coal sample (ΔP index) is correlated with data from pilot scale slurry pipeline tests. The ΔP index is related to coal micro-fissuration and hence to friability. Four coal samples of 50 mm top size, ranging from subbituminous to medium-volatile bituminous, were used for attrition testing in a 158 mm diameter pipeline after pumping for one to four hours. Several samples were collected for analysis to determine size degradation and for the laboratory measurement of the ΔP index.

The results indicate a linear relationship between the ΔP index and the amount of minus 0.6 mm coal generated during the pipeline attrition tests. Similarly, the coals with higher ΔP indices showed greater amounts of minus 0.1 mm material. It is suggested that the rate of gas desorption, as indicated by the ΔP index, is dependent upon the degree of fissuration of the coal sample and the greater the fissuration, the greater the size degradation during slurry pipeline transport. The relationship between the amount of fines produced during attrition in the pipeline and the ΔP index can then be used for qualitative predictions of the size degradation that will occur during slurry pipeline transportation of other coals.

Introduction

The tendency of coal to break in handling is termed friability. This depends on the toughness, elasticity, fracture characteristics and strength of the coal. Coal is not homogeneous in its physical make-up and its resistance to degradation is influenced by such factors as maturity, frequency of cleating and the presence and nature of bedding and fracture planes. The concern here is not with the intentional size reduction through mechanical comminution (crushing), but with the unplanned generation of fines by collision between particles and abrasion of particles during mining, handling and processing.

The re-distribution of stresses attributable to the making of mine openings, to the amount and type of explosives used and to increasing mechanization of mining techniques contributes to the formation of planes of weaknesses and tends to increase the proportion of fines in the mined coal. Coal particles travelling along chutes, conveyors and bins and through preparation equipment are subjected to impact and friction with adjacent particles and walls, causing size degradation. Degradation of coal particles occurs during slurry pipeline transport as a result of attrition during pumping and due to impact and abrasion with other particles and with the pipe wall. Excessive amounts of fines, particularly super fines (minus 44 μm), can greatly increase dewatering and drying costs at the final pipeline destination.

The relative friabilities of different coals is of great importance in handling, preparation, transportation and separation of the coal slurry. A large amount of fines (particularly minus 44 μm) in the coal slurry result in a high viscosity and higher pumping costs than for slurries with fewer fines[1]. The dewatering cost also increases rapidly as particle size becomes smaller. For example, dewatering costs of minus 6 mm fine coal are approximately ten times those of the plus 6 mm coal[2]. On the other hand, reduction in size can have beneficial effects on the overall cost of coal slurry transportation itself. For example, friable coals require less crushing, meaning reduced power and capital cost requirements for crushing and grinding. Similarly, coals containing embedded or inter-grown clays which tend to swell and disintegrate in water, causing a change in size distribution, may show improved washability characteristics and better quality after dewatering.

This paper reviews existing methods used to predict coal size degradation during slurry pipeline transport and compares data from pilot scale pipeline attrition tests with indirect measurements of micro-fissuration of four western Canadian coals.

Fissuration - Size Degradation

The physical structure of coal is characterized by pores and fissures of varying sizes which influence many of its chemical, physical and mechanical properties. These properties include such things as friability, gas sorption characteristics, moisture capacity and coking properties. Fissures can be naturally occurring or mancaused. Natural fissures are formed during the process of coalification. Tectonic movements (involving compression and tension or shear) to which a coal seam may have been subjected are a cause of fissuration, as is oxidation or weathering of seams close to the surface. Tectonic movements are the major cause of extensive fracturing of coal in the mountain districts.

Brown indicated that breaking of coal to fine fractions depends on the inner state of the piece (e.g., fissures and pre-stresses), and the way in which the breaking forces are applied in relation to the fissures.[3] Stefanski stated that a coal's tendency to degradation cannot be considered a constant property but rather is a function of the degree of micro-fissuration, that is the proportion of the weakest components in the sample, weakened further by fissures produced during mining.[4] He developed a method to characterize and compare types of handling and preparation equipment in relation to the amount of degradation they created. The objective was to determine the degradation effect of a unit independent of the properties and size distribution of the coal. He used a drop shattering index test, in which a coal sample of given size (20-80 kg) was loaded in a standard steel box, dropped from a given height ($h_1 = 2$ m) onto a rigid plate and the amount of degradation determined. He indicated that the degree of degradation is a function of the speed of impact against the rigid plate. The test can be applied to cases involving the degradation of coal particles on impact and falling but it is not suitable for disintegration in water during preparation or for impact and abrasion during pumping in slurry pipelines.

LePage and Pollard have developed a wet attrition test to predict the amount of degradation of coal, shales and clay particles.[5] The objective of the test is to treat the coal on a laboratory scale under conditions simulating commercial scale operations. In this test a 50 kg sample of coal is tumbled with 150 kg of water in a 200 liter steel drum at 20 rpm. The duration of tumbling depends on the retention time in the system used. A standard number of 50 mm steel cubes are included with the coal in the tumbler to simulate attrition caused by pumps.

Mikhail and Patching found a close relationship between the coal micro-fissuration and the amount of minus 0.6 mm material in run-of-mine coal.[6] A laboratory procedure was adopted (ΔP) to measure, under standardized conditions, the initial rate of methane desorption. This study suggested, and later was supported by other work, that coal micro-fissuration is independent of the method of handling. This was indicated by evidence of a linear relationship between the amount of minus 0,6 mm sizes resulting from tumbling coal and ΔP index values and it suggested that fines production is independent of the top size.[7]

Methods for Predicting Size Degradation in Slurry Pipelines

Pilot Plant Loop

A coal slurry with a predetermined per cent solids is run through a pilot scale loop. The loop includes a sump pump, a closed circuit pipeline and sampling and monitoring systems. The slurry is recirculated for a certain period of time and representative samples are collected for size analysis. Size analyses of the coal before and after attrition are compared to determine the amount of degradation after a specific time in the slurry pipeline loop. Degradation results from impact during pumping and from friction between adjacent pieces of coal and between the coal particles and the pipe wall. The test is reliable in determining degradation under pressures similar to those which exist in an actual pipeline. However, the number of cycles through the pump are usually more than would occur in an actual operating pipeline and this results in an unusually large amount of fines for a given attrition time.

The Wheel Stand

The wheel stand consists of a pipe of diameter D bent into a wheel of diameter D_k. Both pipe diameter and wheel diameter are dependent on coal particles size (ratio of average coal particles diameter to pipe diameter). Slurry is poured into the wheel to a level of one third to one half of the capacity of each pipe ring. The slurry slides relative to the moving walls of the rotating wheel, just the opposite of actual pipeline flow but with similar hydrodynamic behavior.[2] Circularity of the wheel and wheel balancing are important factors. Overfilling the wheel beyond ⅓ to ½ capacity places solids in the ascending portion of the pipe where gravity distributes the concentration of solids uniformly and reduces the effect of wall contact. The wheel stand provides much of the data a pipe loop test offers on a smaller scale but it does not include degradation resulting from impact during pumping.

EXPERIMENTAL STUDIES

Four samples of coal (20-40 tonne) including one subbituminous and three medium-volatile bituminous coals were used for the attrition and hydraulic tests. All samples were crushed to a top size of 50 mm before pipeline testing. The subbituminous and one of the bituminous samples were raw coal while the other two bituminous samples were washed coal.

Pipeline Attrition Tests

The pipeline attrition test for each coal consisted of loading approximately two tonnes of the coal into a 158.5 mm pipeline test loop, pumping the resulting slurry around the horizontal loop and withdrawing samples at fixed time intervals. Particle size distribution and ΔP index were determined for each sample.

The 158.5 mm pipeline test loop consisted of a 12 x 10 Wilkinson rubber lined centrifugal pump driven by a 250 hp motor, a magnetic flowmeter, a heat exchanger, a feed tank and 38 m of pipeline on the outgoing leg of the loop. From the pump the slurry passed through the flowmeter and heat exchanger prior to reaching the outgoing leg of the pipeline loop. After making a 180° turn through a wide sweeping bend, the slurry returned through a 41.5 m straight test section of pipe to the suction side of the pump. Eight victaulic couplings and eight bolted flanges held the various sections of the pipeline test loop in place. Samples for particle size analysis and the ΔP index determination were obtained by means of a 100 mm diameter centre stream sampler located in the pipeline immediately after the pump discharge. This sampler was shaped like a pilot tube, faced upstream, could be moved to any position between the top and bottom of the pipe and was completely withdrawn from the pipe cross section when not sampling slurry. Earlier testing showed no significant difference between the particle size distributions of samples taken with the centre stream sampler located at the centre of the pipe and full pipeline discharge samples.

Coal was added to the system through an overhead hopper located inside the feed tank. The hopper discharged into the bottom of the feed tank which discharged into a tee in the pipeline test loop immediately ahead of the pump. The feed tank was operated with as low a liquid level as possible which was sufficient to avoid air entrainment (about 1 m above the axis of the pump inlet).

An attrition run consisted of the following steps. A predetermined amount of coal, sufficient to give the desired solids concentration (50% to 60% by mass) in the test loop, was placed in the overhead hopper. The loop was filled with water, then coal was added down through the bottom of the feed tank into the loop and the equivalent volume of water was displaced up into the feed tank. Circulation of water around the loop was maintained at a low rate so that the coal bedded out around the loop. A short recirculation line running from the pump discharge to the top of the feed tank provided water to wash all the coal from the feed tank into the suction side of the pump. Loading took approximately 10 minutes after which the slurry circulation rate was set at 2.95 metres per second and the first sample for particle size distribution and ΔP index determinations was withdrawn through the centre stream sampler. This sample represented slurry conditions at the start of an attrition run. Succeeding samples were taken after 1 hour, 2 hours and 3.5 hours or 4 hours. Circulation rate throughout the run was maintained at 2.95 metres per second.

ΔP Index Measurements

The coal structure contains pores and fissures of all sizes from a few ängstroms to several millimetres. Pores function as gas reservoirs whereas fissures act as transport arteries. The rate of desorption of gas from coal is initially very rapid and depends on the degree of fissuration. Khodot el al[8] indicated that coal friability is associated with the presence of a large number of fissures <5 μm in thickness. A useful indicator of fissuration is the ΔP index, which characterizes the initial rate of desorption of methane from coal which depends on the micro-fissuration and perhaps on the size and distribution of pores in the coal structure. The index is measured on coal samples which have first been evacuated and which are subsequently saturated with methane under pre-determined conditions. The ΔP index apparatus[9] used in the present study was built to the same dimensions as the one designed by CERCHAR* (used there to characterize coals in relation to susceptibility to gas outbursts).

Stage preparatory crushing and screening were used to prepare samples with a size range of $<0.5>0.25$ mm. Briefly, for the standard ΔP tests, 3 g portions of coal of $<0.5>0.25$ mm size are placed in metal cups of 7 cm^3 volume and are first degassed for 1.5 h. The samples are then saturated with the helium for 10 minutes at exactly 101.23 kPa (1 standard atmosphere of pressure) and then connected, one at a time, with a manifold of 19 cm^3 volume which has been evacuated before each sample is connected to it. The pressure in the manifold caused by the release of helium is measured in a connected manometer after ten seconds and is recorded as P_1 mm of mercury**. This indicates the volume of the interstitial space in each case, because helium is not sorbed by the coal. The samples are again evacuated and then saturated for 1.5 h with methane at 101.23 kPa. They are again connected with the manifold, one after another, the manifold being evacuated before each sample is tested and the pressure shown by the manometer after 60s (P_2 in mm of mercury) is noted. The following value is calculated:

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* CERCHAR Centre d'études et recherches des charbonnages de France

$$\Delta P = P_2 - P_1 \text{ (in mm of mercury)}$$

The ΔP indices are empirical values which depend on the test being carried out according to standard procedure and in equipment of standard size. As such they provide a means of comparing the rates at which gas can be released from different coals. The movement of gas out of coal particles probably occurs in two-stages, with the gas first desorbing and diffusing through the fine pore structure and then flowing more rapidly through any fissures present[7]. Determinations of the ΔP index are carried out on at least two portions from each sample. Results usually agree to within 2 units (i.e., 2 mm); if not, additional runs are made.

A split from samples A, B, C and D from the pipeline attrition tests were used for ΔP measurement.

Discussion of Results

Size distribution graphs of coals A, B and C before and after attrition tests in a closed loop pipeline (158.5 mm I.D.) are shown in Figures 1, 2 and 3. Samples B and C are clean coal (bituminous) and known to be friable having a Hardgrove Grindability Index (HGI) ranging between 100 and 150. Coal B indicates relatively parallel degradation (Figure 2) in all size ranges with increasing attrition time, while Coal C (Figure 3) shows a considerable increase in the amount of fines (minus 0.2 mm) at the expense of coarse particles (plus 2 mm). Coal A is subbituminous and with HGI = 45 would be considered less friable than coals B and C. However, coal A showed high amounts of the minus 0.1 mm fraction (Figure 1). This may have been caused by oxidation of the sample as it was exposed to weathering for about one year before being tested in the pipeline loop. Low rank coals generally tend to become more brittle and dusty when oxidized. Coal A shows approximately parallel size reduction by degradation of the plus 1 mm fractions and

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** 1 mm Hg = 133.2 Pa

an increase in the amount of slimes (minus 0.1 mm) compared to the more friable coals B and C. The rate of increase in degradation due to attrition decreased with increasing attrition time and this decrease is more obvious in the highly friable coal (B) than the relatively less friable one (A).

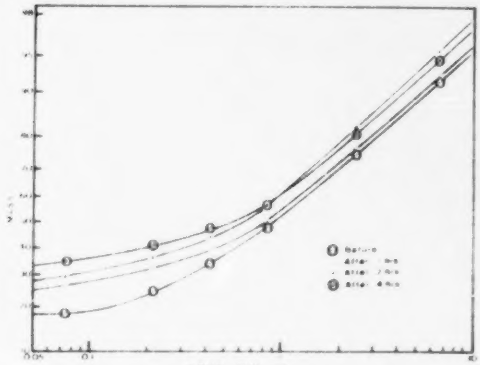

Figure 1 Size Distribution Before and After Closed Loop Pipeline Attrition Run. Sample A

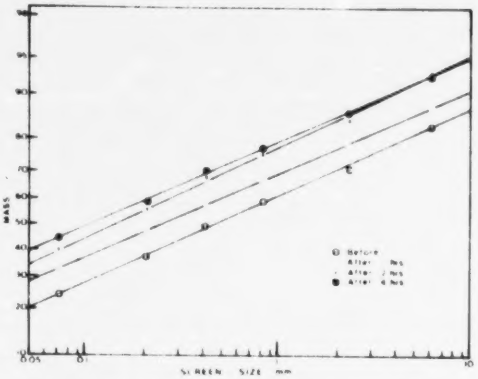

Figure 2 Size Distribution Before and After Closed Loop Pipeline Attrition Run. Sample B

The average ΔP measurements and attrition data for the four coals are summarized in Table 1. Relationships between ΔP indices and percentage of minus 0.6 mm and minus 0.1 mm fractions are shown in Figure 4. The linear relationship between ΔP and percentage mass of the minus 0.6 mm fractions after three periods of attrition in the closed loop pipeline demonstrate the link between micro-fissures as indicated by ΔP index and degradation that occurs in the pipeline. Figure 4 also shows that the rate of degradation decreases with increasing attrition time. The linear relationship of minus 0.6 mm mass per cent and ΔP index for the three coal samples indicate that the amount of degradation is similar, irrespective of differences in coal friability. Figure 5 shows that the rate of increase of fines is high initially and then tapers off. For the least friable coal (A), the increase in the amount of minus 0.6 mm with time is more gradual. As indicated by its low ΔP value, this less friable coal contains fewer fissures than the highly friable coal (B) and therefore tends to break gradually during impact and friction. On the other hand, coal B, with an extensive network of fissures, breaks readily at an earlier stage of attrition and later stabilizes to a more gradual degradation rate.

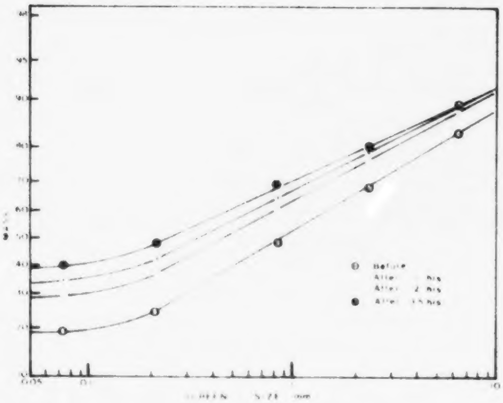

Figure 3 Size Distribution Before and After Closed Loop Pipeline Attrition Run. Sample C

Sample	Average ΔP	Mass % of minus 0.6 mm after attrition time of			Mass % of minus 0.1 mm after attrition time of		
		1 hr	2 hrs	4 hrs	1 hr	2 hrs	4 hrs
A	12.5	43.0	49.0	51.2	27.0	30.5	36.0
B	31.3	62.5	72.0	73.5*	37.5	45.0	49.0*
C	22.4	55.0	59.0	63.2	30.8	36.5	41.0
D	17.3	47.0					

* 3.5 hrs attrition time

TABLE 1 ΔP Measurement and closed loop pipeline (158.5 mm I.D.) attrition data

The plots in Figure 4 also show an increase in the amount of minus 0.1 mm slimes as the ΔP values increase. The amount of slimes resulting from attrition are approximately comparable for coals A, B and C, particularly after one hour of attrition (Figure 5), and appears to be independent of the degree of fissuration. The non-linearity of the relationship between ΔP and the mass per cent of minus 0.1 mm coal is probably due to the fact that the P values are determined only on the 0.5 to 0.25 mm size fraction. The production of minus 0.1 mm material may not

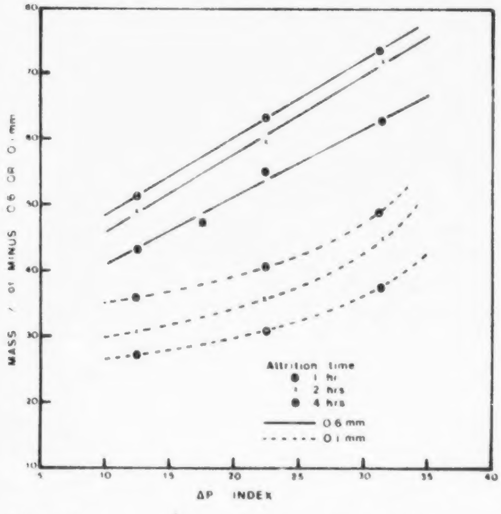

Figure 4 ΔP Index Versus Mass of <0.6 mm and 0.1 mm After Attrition in Closed Loop Pipeline

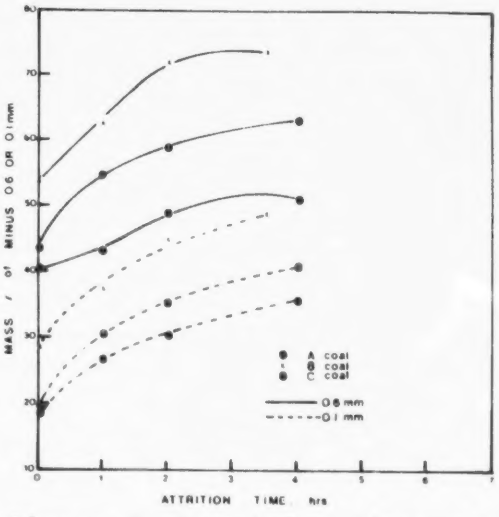

Figure 5 Attrition Time and Fines Generation

only be related to the breakage of coal along micro-fissures but also to grinding and attrition processes that are not directly related to the micro-structure as measured by the ΔP experiment.

The relationship between the mass per cent of fines and ΔP measurements is to be tested by further work and, if confirmed, should be of significant value. The amount of fines in coal transported by pipeline could thus be predicted at an early stage of development by determining its average ΔP index from a number of samples and applying the linear relationship. Knowing the amount of minus 0.6 mm at the end of the pipeline is important, as it determines the size, design and cost of dewatering and drying facilities.

Conclusion

Four coals from western Canada were tested in a closed loop pipeline to determine degradation and representative samples were collected for ΔP index measurements. The pipeline tests indicated that the rate of degradation due to attrition decreased as attrition time increased. The decrease was more obvious in a highly friable coal than with a less friable one. A linear relationship was found between the ΔP values and percentage mass of minus 0.6 mm coal after three stages of attrition lasting 1, 2 and 4 hrs. respectively, in the pipeline. This demonstrated the link between micro-fissuration as measured by ΔP index and degradation due to attrition in the pipeline. The relationship between the ΔP values and the amount of minus 0.1 mm slimes showed that an increase in the amount of slimes generated by attrition corresponded to an increase in ΔP values.

The amount of fines in coal transported by pipeline could be predicted at an early stage of development by determining a coal's average ΔP and applying the relationship discussed earlier. Further work will be done to obtain more data from a pilot scale pipeline loop and to correlate the amount of fines generated with the wheel stand tests and ΔP index measurements.

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Questions on Paper by Mikhail

Q: What kind of coal did you test?

A: Three metallurgical coals, and one sub-bituminous foothills coal.

Q: What is the effect of the pump and the pipeline? We found that pumping the coal through the pump resulted in as much degradation as pumping it through 130 metres of pipeline.

A: No similar experiment has been done in Canada.

Q: Did you do any calculations with specific coal?

A: Most degradation occurs in silos from the mine mouth to the preparation plant. After this initial degradation the coal appears to stabilize.

Geller: The Influence of Degradation at the Hydraulic Conveyance of Coarse Washed Dirt on the Dimensioning of Dewatering Installations

The Influence of Degradation at the Hydraulic Conveyance of Coarse Washed Dirt on the Dimensioning of Dewatering Installations

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In the German coal mining industry the underground disposal of coal mine wastes is at the moment carried out in minecars exclusively. Since this conventional transport involves considerable disadvantages, an alternative seems to have been found in the hydraulic transport. Apart from the general advantages of a pipeline transport system, use was to be made of the gravity of the dirt which was to be transported underground through a single transport pipe.

The basic principle of this hydraulic transport technique is presented in fig. 1: the stowing dirt is continuously fed via a conventional transport system into the downpipe. The drive water, necessary for the transport of the stowing dirt Q_{TW}, is fed from the water container through a control valve RV_{TW} into the mixing zone of the accelerator jet, there taking up the stowing dirt from the settling pipe. In the bottom part of the accelerator jet the slurry (of water and dirt) is accelerated to the velocity required for the transport in the horizontal transport pipe.

Without the use of additional water Q_{ZW} there is a static water column in the settling pipe above the accelerator jet. This, however, would cause danger of plugging in the settling pipe, since the finest particles in the slurry have a very low settling velocity and would thus increase the density of the carrier fluid. For this reason additional water Q_{ZW} is fed to the settling pipe via a bypass pipe so that for safety reasons the spatial volumetric concentration does not exceed 40 per cent. Thus the volumetric flow rate of the bypass water has a flushing effect.

By means of the control valve RV_{TW} the water column in the settling pipe is adjusted to a level, the pressure of which is able to provide the acceleration energy, to overcome the relatively small losses in the accelerator jet, and above all to cover the pressure drop in the horizontal transport pipe. Thus the height of the settling pipe becomes a function of the length of the horizontal transport pipe. In a pipe with a diameter of 209 mm at an average

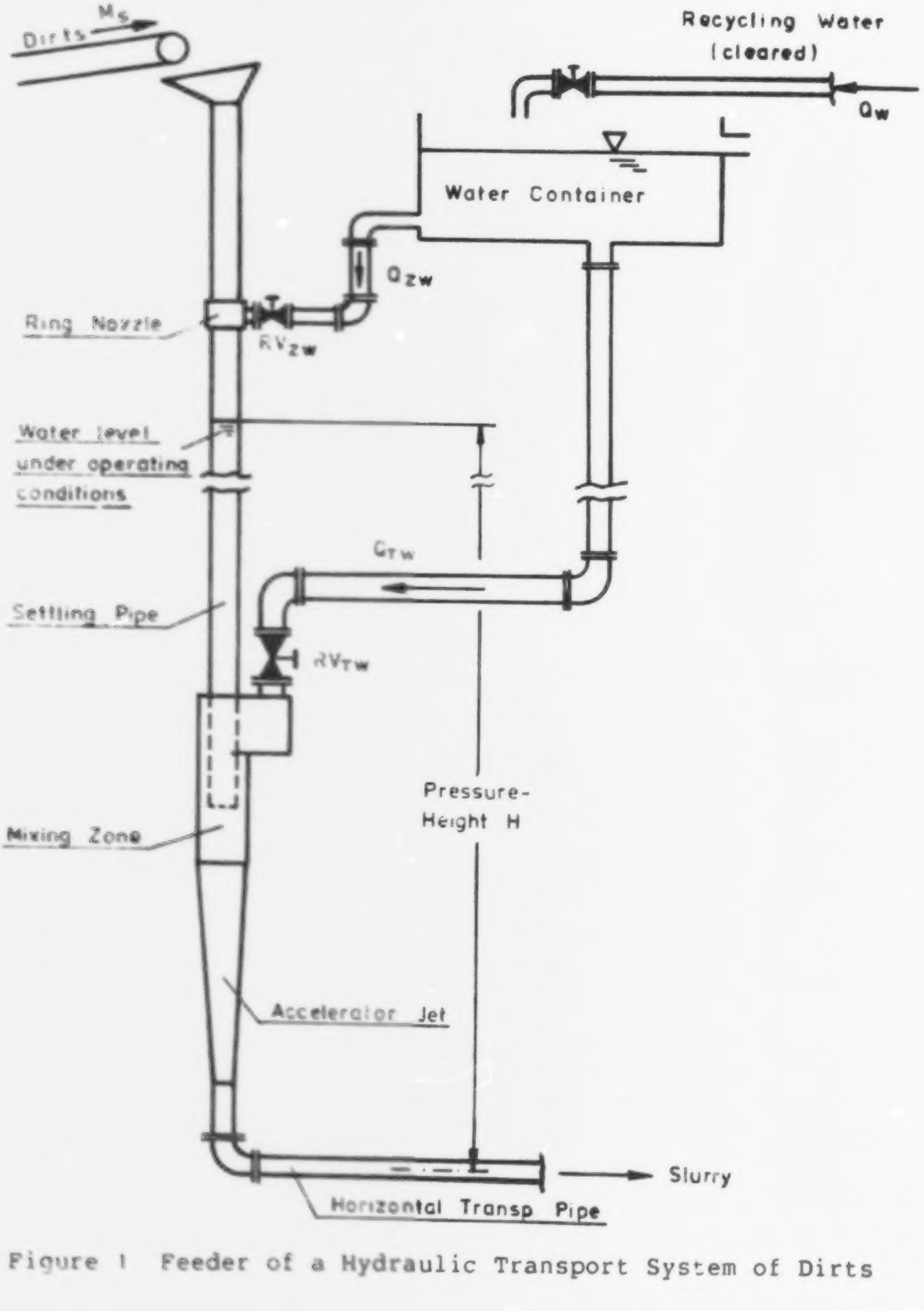
Dirts
M_S
Recycling Water
(cleared)
Q_W
Water Container
Q_{ZW}
Ring Nozzle
RV_{ZW}
Water level
under operating
conditions
Q_{TW}
Settling Pipe
RV_{TW}
Pressure-
Height H
Mixing Zone
Accelerator Jet
Slurry
Horizontal Transp Pipe

Figure 1 Feeder of a Hydraulic Transport System of Dirts

transport velocity of 4.5 m per second and with a delivered concentration by volume of about 15 per cent, the pressure gradients for a volumetric flow rate of coarse dirt 200 tons per hour are about 1.4 to 1.5 bar per 100 m, according to the composition of the dirt. Consequently for a horizontal transport pipe of 1000 m, a water column in the settling pipe of 150 m is required.

At the end of the horizontal transport pipe the dirt is separated from the water in adequate dewatering installations. Since particle diameters of more than 63 μm up to 80 mm don't cause any problems in the process, these are then transported conventionally to their range of application - usually pneumatic stowing - whereas the slurry water with finest particles less than 63 μm has to be clarified before being fed back to the water container by means of centrifugal pumps. Thus the water is recirculated.

For the investigation of the hydraulic transport technology of stowing dirt, laboratory tests were carried out at Fachhochschule Bergbau of WBK Bochum in 1974 and full-scale tests at Sachsen Colliery of BAG Westfalen in 1976. The results of these investigations led to the erection of a surface test rig at Ewald Colliery of BAG Lippe in 1978 with the aim to test again the essential elements of the installation in full scale. In a first test series in 1979 the operational reliability of the installation as far as flow technology is concerned could be proved. In 1980 the test rig was extended. In 1981 extensive tests for the determination of the degradation of the dirt, when being transported through the installation, could be carried out. Fig. 2 shows the test rig used for these investigations. The essential part of this installation is identical with that in fig. 1 (For technical reasons two water containers are installed there).

The next slide shows the tower of the test rig. In the centre are to be seen the sinking pipe, the accelerator jet and the horizontal transport pipe with regulating valves.

The next slide shows the dewatering installations.

Most mining dirt in the Ruhr consists of quartz-free shales with a very low degree of hardness and thus with a high tendency towards disintegration and degradation. The swelling effect of the alumina included in shale beds is also of negative effect, especially when the dirt is in contact with water over a longer period.

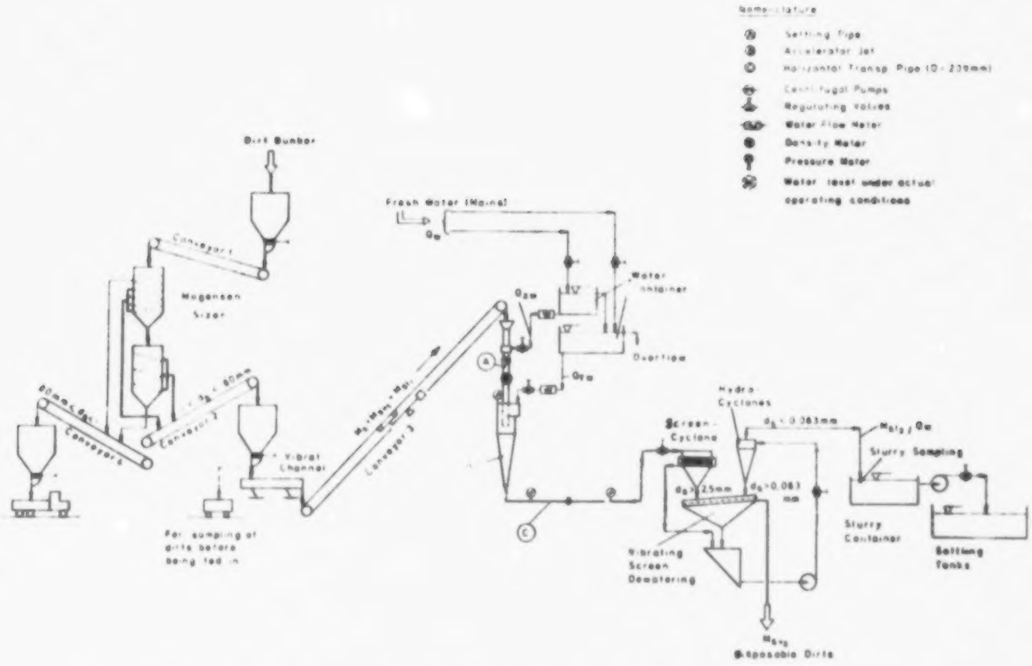
Nomenclature
Ⓐ Settling Pipe
Ⓑ Accelerator Jet
Ⓒ Horizontal Transp. Pipe (D=200mm)
Centrifugal Pumps
Regulating Valves
Water Flow Meter
Density Meter
Pressure Meter
Water level under actual operating conditions
Dirt Bunker
Conveyor 1
Mogensen Sizer
Conveyor 2
Conveyor 3
Conveyor 4
Vibrat. Channel
For sampling of dirts before being fed in
Fresh Water (Mains)
Water Container
Overflow
Hydro-Cyclones
Screen-Cyclone
Vibrating Screen Dewatering
Disposable Dirts
Slurry Sampling
Slurry Container
Settling Tanks

Figure 2 Scheme of the test rig "Recklinghausen II"

TABLE
Investigated Dirts of various Collieries of Ruhrkohle AG [13]

No.	Colliery	Area	Content of Shale (pure) in %	Content of Sand-stone (pure) in %	with/without Flotation Dirt	Wanted Classification in mm	$d_{50/0}$ in mm	Portion $\frac{M_{sl}}{M_s}$ of Finest Grain < 0,063 mm in %: when fed into Loop (L_0)	after Transport through a Loop of L_1=218m	L_2=920m	L_3=4900m
	1	2	3	4	5	6	7	8	9	10	11
1	Gen.Blumenthal	Lippe	47	10	with Flot.	0 - 80 1)	16,5	5,3	7,9	10,3	27,3
2	" "	"	43	7	" "	0 - 80 1)	21,2	4,7	6,1	10,9	23,9
3	" "	"	43	10	" "	10 - 80 1)	20,9	5,7	7,6	11,3	25,8
4	Consolidation	Lippe			without Flot.	0 - 80 1)	16,5	3,8	5,1	9,0	18,0
5	"	"	51	5	" "	10 - 80 1)	14,2	4,2	4,7	7,5	19,0
6	Westerholt	Lippe	51	5	without Flot.	0 - 80	10,6	12,4	12,9	21,3	41,5
7	"	"	51	2	" "	0 - 80	15,9	10,6	13,3	20,8	47,7
8	Prosper	Niederrhein	55	3	without Flot.	0 - 80	18,3	4,8	7,5	11,0	31,8
9	"	"	38	7	" "	0 - 80	21,9	4,4	6,6	8,6	30,6
10	"	"	41	8	" "	0 - 80	12,0	5,5	6,9	10,9	35,3
11	Minister Stein	Westfalen	44	6	without Flot.	0 - 80 2)	15,8	4,7	7,2	8,8	11,4
12	" "	"	44	7	" "	10 - 80 2)	14,1	3,7	5,3	7,4	19,8
13	Ewald	Lippe	63	1	with Flot.	10 - 80	10,3	3,5	4,2	6,4	15,7
14	"	"	67	3	without Flot.	10 - 80	16,5	2,7	3,7	6,1	15,8

1) no screening effect 2) obvious screening effect

The mining dirt in the Ruhr contains only little sandstone which, due to its hardness, appears to be very suitable for hydraulic transport at first sight. On the other hand this hardness causes enormous equipment wear.

Since obviously only certain kinds of mine wastes can be used for hydraulic transport, Ruhrkohle AG decided to test the washery dirt of the collieries General Blumenthal, Consolidation, Westerholt, Prosper, Heinrich Robert and Ewald.

The dirts of these collieries are a representative cross-section of all mine dirts in the Ruhr - ranging from those possibly suitable for hydraulic transport to those entirely unsuitable.

They are all characterized by their high content of clayshale of between 40 and 60 per cent and their low content of sandstone of between one and ten per cent (see columns 3 and 4).

Since these were field trials, the dirt was not prepared especially, but taken from the running production. Thus the washery shales were mixed partly with flotation dirts (see column 5).

The average moisture content of the wastes was about six per cent. The influence of preliminary screening on the final content of finest grain less than 63 μm was investigated too (see column 6). The screening at zero to 80 mm means that only the overflow more than 80 mm is screened off, whereas the 10 to 80 mm screening aimed at screening-off as much of the finest grain less than 63 μm as possible before the dirt was fed into the hydraulic transport system. This was, however, not achieved to our satisfaction due to the relatively high moisture content and the clayey character of most dirts, which is also proved by the d_{50} - feed-in-values in column 7. Since the finest grain passed the screens as material adhered to the larger particles, it was not possible to separate it completely from the dirt.

Columns 8 to 11 show results presented later in diagrams. As could be expected the performance characteristics of different kinds of those dirts varied gravely.

It was the main task of the test series to investigate the influence and the functional connections of the various parameters such as mass flow rate of dirt, the delivered concentration of volume, average transport velocity and others on the degradation.

The tests carried out according to the scheme in fig. 2 have produced as results the relations presented in fig. 3. The performance characteristics are limited by the plugging curve of the transport pipe and by the boundary line of the test rig depending on its height (about 16.5 m).

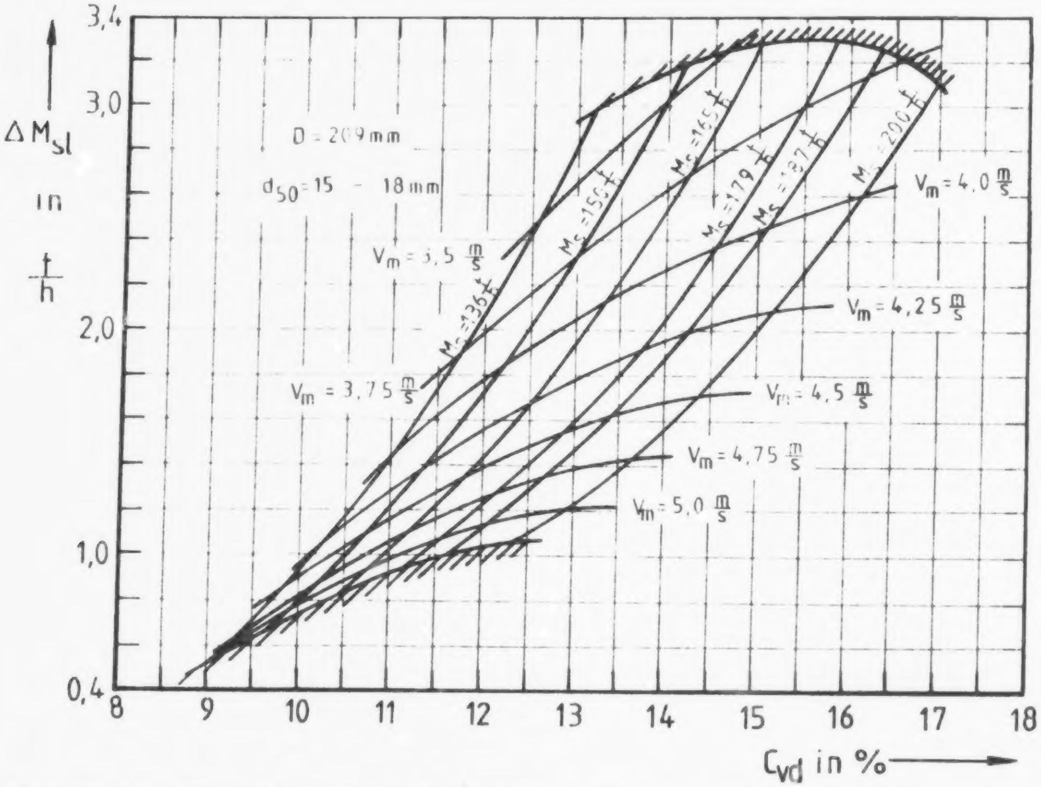

Figure 3 The increase of ΔM_{sl} of finest grain d <0.063 mm depending on various factors of influence [12]; (Explanations: see Appendix)

The essential result at first sight is that the increase of finest grain with a diameter less than 63 μm is relatively small. For the mass flow rate 200 t/h and the delivered concentration 15 per cent it is only about one per cent. Another result is that at decreased transport velocity and at constant mass flow rate of dirt that is with increased delivered concentration, the values for ΔM_{sl} in some cases increase considerably. This seems to be influenced by the different flow behaviour of solids at low velocities and sliding transport on the pipe bottom in contrast to higher velocities and floating transport.

Fig. 4 gives a concise presentation of the results of the test series at "Recklinghausen II". The absolute values M_{s2} of finest grain with particles less than 63 μm after transport through the test rig for dirts of various collieries are shown as a function of the transport velocity and of the mass flow rates M_s. Basically the same tendency as already discussed in fig. 3 can be seen: The amount of slurry increases with decreasing transport velocity. Only the dirt from "Prosper" Colliery again shows increasing degradation at velocities of 5 m per second and more. Because of its strong clayey consistency extreme values had been expected anyhow. Together with the dirt from "Westerholt" Colliery which is also not suitable for hydraulic transport, it is an exception and cannot be considered in a valuation analysis.

Disregarding these two kinds of dirt, it can be said that the maximum percentage of M_{ml2} to M_s of the remaining kinds of dirt is not essentially higher than five per cent and depends primarily on the amount of finest grain less than 63 μm which, as adhesive grain, was part of the dirt when fed into the installation. All tests showed as a special result that the mechanical details characteristic of the test rig "Recklinghausen II", as settling pipe, acceleration jet, screening cyclone and hydro-cyclones, were of relatively small influence on the increase of finest grain.

At the test rig "Recklinghausen II" only a rather short horizontal transport pipe with a length of 55 m could be installed. For this reason long-time degradation tests could not be carried out here. These were carried out at the hydraulic test loop of Bergbau-Forschung of Steinkohlenbergbauverein in Essen with the same material as at the test rig "Recklinghausen II".

Bergbau-Forschung has a hydraulic test rig with a pipe diameter of 250 mm and a loop length of 234 m. Two hundred and eighteen meters beyond the feed input, a sampler is installed by means of which the grain size distribution of the dirt was determined after 218 m, 920 m and 4900 m.

All tests were carried out at an average velocity of 4.5 m per second, a delivered concentration by volume of about 17 per cent and with the density of solids of 2.5 tons per cubic meter at a mass flow rate of solids of about 340 tons per hour. These figures differ clearly from the operational data of the hydraulic test rig

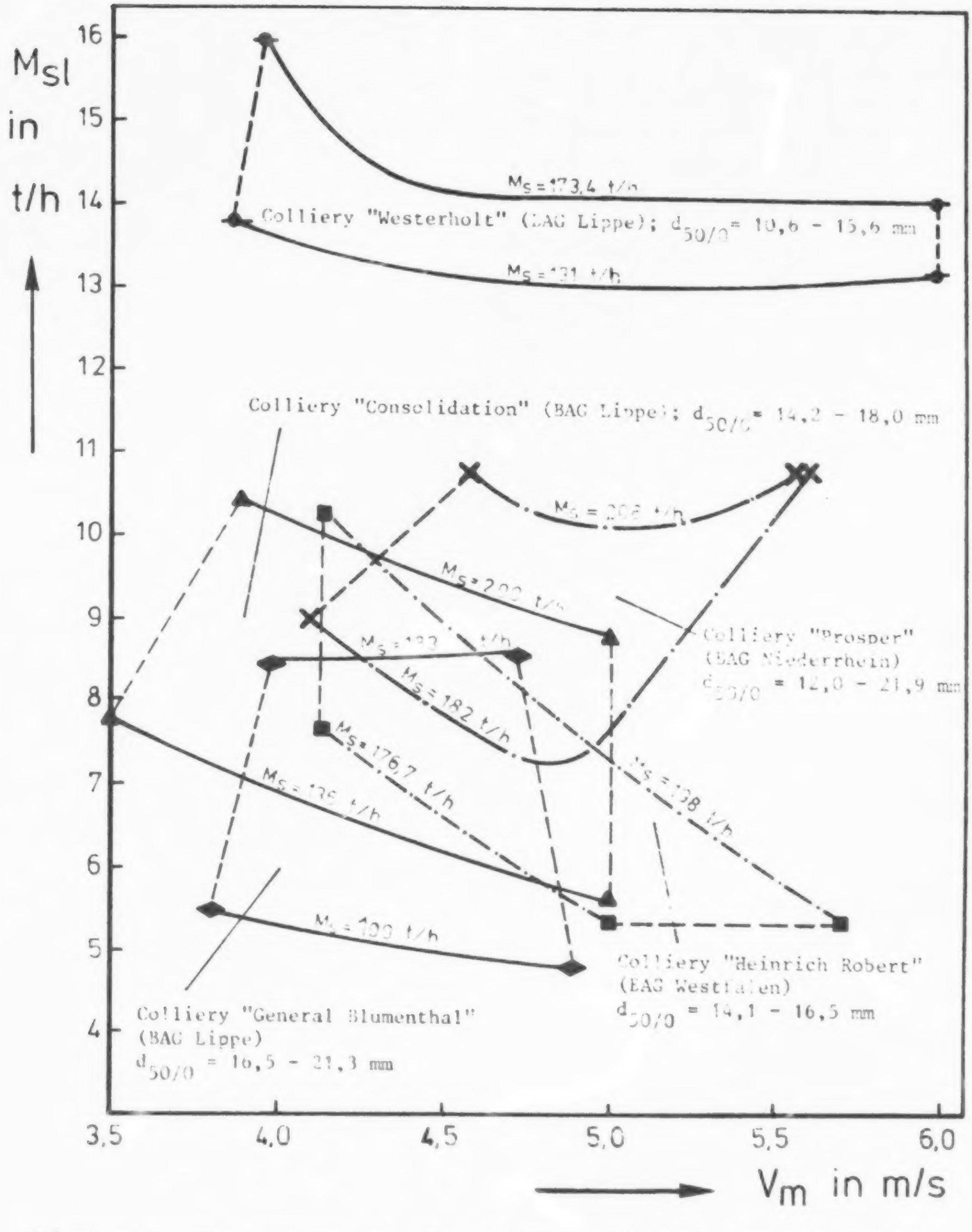

Figure 4 The amount of slurry M_{sl2} with d_s <0.063 mm of dirts from different collieries (measured at the test rig "Re II") as a function of the transport velocity and the mass flow rate of dirt M

"Recklinghausen II" with the same velocity of 4.5 m per second indeed, but 15 per cent delivered concentration by volume, 209 mm pipe and thus 200 tons per hour mass of flow rate.

Regarding the degradation effect the results are not simply transferable, of course.

In fig. 5 the slurry content of the different dirts for the zero to 80 mm classification without the addition of flotation tailings are presented. Similar to fig. 4 the "Westerholt" and "Prosper" dirts here also prove unsuitable for hydraulic transport. The sample of dirt of "Heinrich Robert" Colliery taken at 4900 m could be a reading error, as a comparison with fig. 6 shows. It must be considered that the mass flow rate of dirt doesn't have a homogeneous transport or volumetric concentration over the total length of the loop since, during the transport of coarse material, overtaking processes of medium and smaller particles occur.

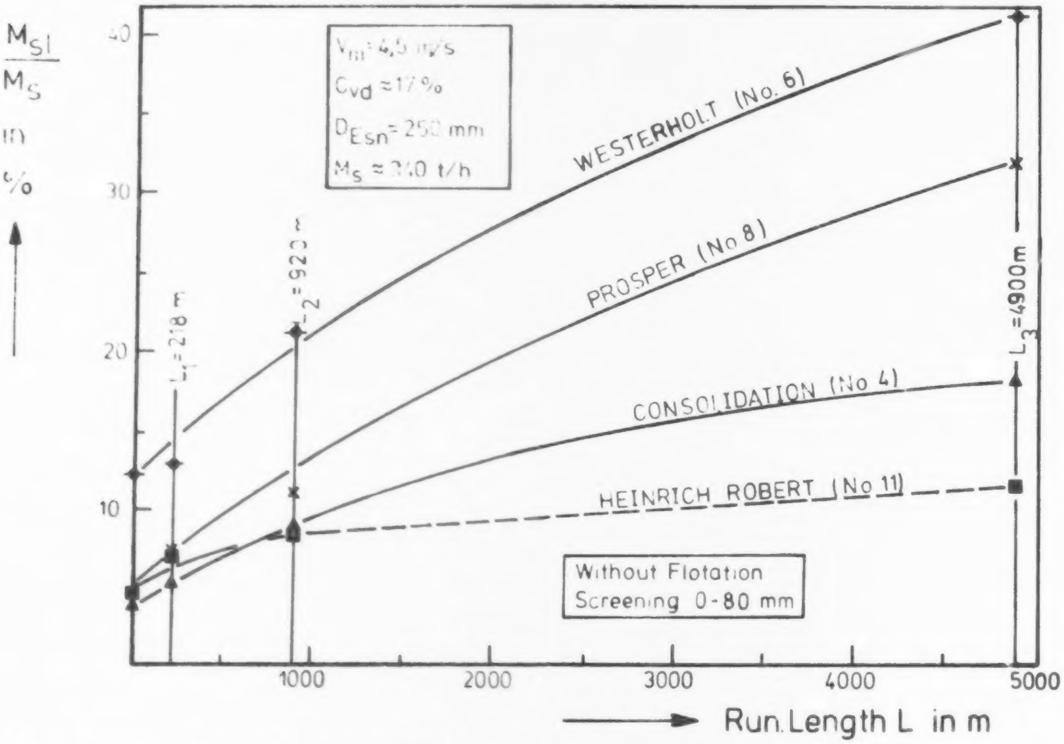

Figure 5 The slurry portions $M_{sl}/M_s < 0.063$ mm of different dirts of the 0-80 mm classification in a horizontal pipe without flotation tailings as a function of the transport length L according to the Table [13]

For this reason it is obvious that the samples taken, due to the instationary flow configuration under otherwise equal conditions, need not always have the same composition - from the temporal as well as from the local aspect. This is also true in connection with the determination of d_{50}-values.

Fig. 6 shows the relations for the ten to eighty mm classification - also without flotation dirt. All dirts considered suitable for hydraulic transport come off relatively well. For the "Heinrich Robert" dirt the results of the 10 to 80 mm classification are worse than those for the zero to 80 mm classification, whereas there are no essential differences for the "Consolidation" dirt. Unfortunately no comparative results for "Ewald" dirt - the most suitable of all investigated dirts - are attainable. The broken curve in fig. 6, showing the results of "Westerholt" dirt according to fig. 5, is to make clear the differences between the negative extremes and those of the more suitable dirts.

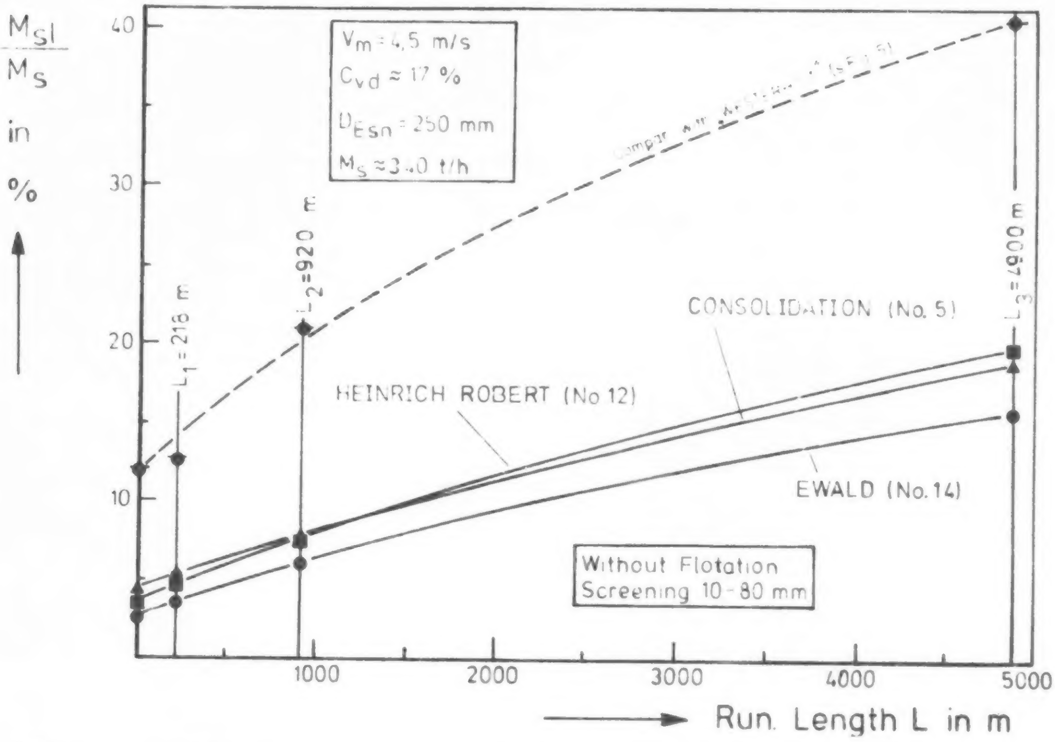

Figure 6 The slurry Portions $M_{sl}/M_s < 0.063$ mm of different dirts of the 10-80 mm classification in a horizontal pipe without flotation tailings as a function of the transport length L according to the Table [13]

Fig. 7 shows the influence of flotation tailings, added to the washery dirt, as well as the influence of different classifications, yet for the different dirts of "General Blumenthal" Colliery and "Consolidation" Colliery. It cannot be taken for granted that the less favourable values for "General Blumenthal" dirt were caused exclusively by the addition of flotation tailings. Yet the differences between the zero to 80 mm and the 10 to 80 mm classifications are very small.

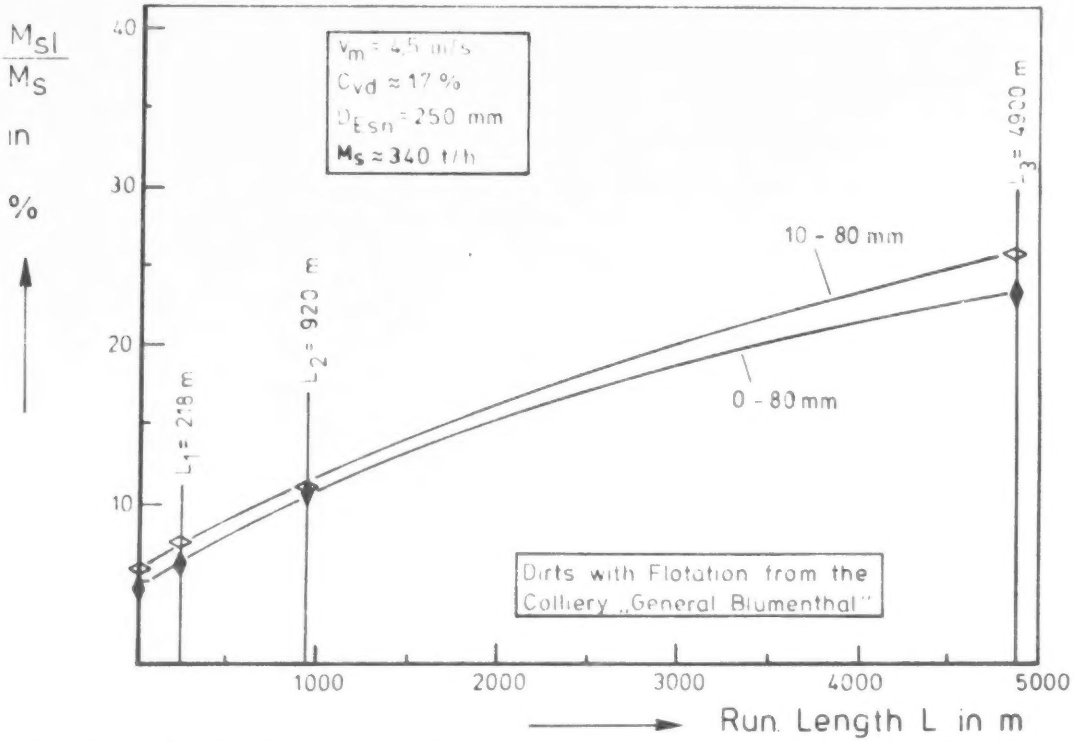

Figure 7 Comparison of the slurry portions $M_{sl}/M_s < 0.063$ mm of dirts of different classifications with reference to the flotation influence as a function of the transport length L according to the Table [13]

A better comparison of the influence of flotation tailings is shown in fig. 8 presenting the figures for "Ewald" dirt. Although the two curves do not differ essentially, it can be seen that the curve for dirt without flotation tailings cuts the curve for dirt with flotation tailings at about 1750 m.

The same phenomenon was noticed during earlier investigations, that is that at the transport of coarse dirt the increase of finest grain less than 63 μm is the greater the smaller the content of finest grain is when the dirt is fed into the hydraulic transport system. This fact can be explained by the different flow behaviours of coarse solids in fluids of different carrier density. The most important results of the investigations can be summarized as follows:

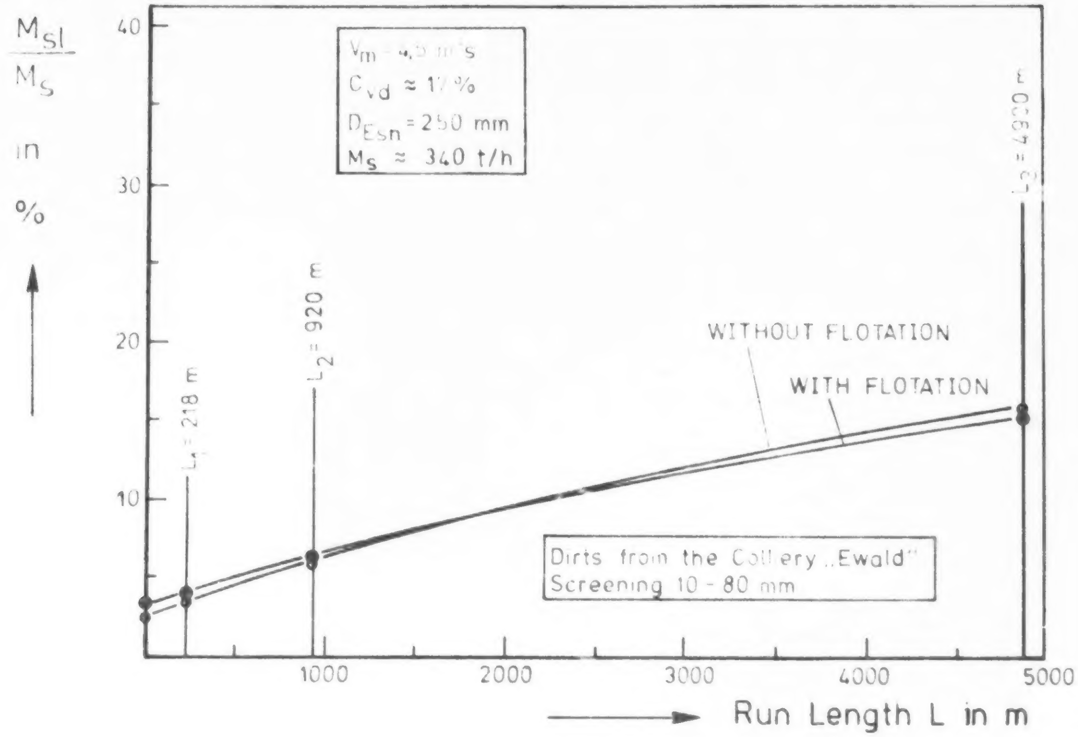

Figure 8 The influence of the addition of flotation tailings on the slurry portion $M_{sl}/M_s < 0.063$ mm of "Ewald" dirt of the wanted 10-80 mm classification as a function of the transport length L according to the Table [13]

Depending on its petrographic composition, washery dirt with certain strength properties can be hydraulically transported over a limited distance. Distances of about 1000 m seem possible. The greatest amount of degradation occurs in the horizontal transport pipe; hardly any, however, in the aggregates characteristic of this transport system.

Coarse washery dirt with a high content of shale is not suited for hydraulic transport, due to its strong tendency towards disintegration and hence the necessity of extensive dewatering installations. Washery dirt with favourable petrographic properties can be transported hydraulically even without a preliminary classification. It is also possible to add a certain amount of flotation tailings to the washery dirt.

The studies were financially supported by funds from the Federal Economics Ministry and Ruhrkohle AG, Bergbau AG Lippe.

Questions on Paper by Geller

Q: Was the degradation in the clay or the shale?

A: In total.

Klose: Effects on Coking Properties of Metallurgical Coal by Pipeline Transportation

Effects on Coking Properties of Metallurgical Coal by Pipeline Transportation

Reinhard Klose, Stahlwerke Peine, Salzgitter AG, Germany

Aim of the tests

The aim of our investigations was to transport the coking-coal hydraulically, over distances of several hundred kilometers, in such a way that it can be fed into coke furnaces, as after conventional rail transport, i.e. with a size range of 0 - 6 mm, and without impairing the coking capacity. In order to achieve this aim, it was necessary to characterize and quantify the factors which influence the hydraulic transportation of coking-coal. The investigations were based on knowledge available at the time gained from the Ohio and Black Mesa pipelines, which transport coal for power plants with a size range up to 1 mm. Coking-coal from 3 different mines were tested. Firstly, the coking-coal was prepared to the same size distribution ready for the tests. The critical velocity as a function of the concentration clearly shows that the 3 coal/water mixes are suspensions with different rheological behaviour. The seam is a major factor in determining a grain's susceptibility to abrasion, during hydraulic transportation. A reason for this behaviour can be found in the hardness of the coal, and in its maceral composition. The investigations carried out alongside the hydraulic transportation tests covered changes in the size distribution, changes of density within the individual fractions, changes in the maceral composition of the grain fractions, changes in the specific surface and in the flow characteristics. Investigations were also made into the effects on the coal's coking properties and on the transport water. The dewatering behaviour was investigated on an industrial scale, as was the coking behaviour in industrial-sized test ovens.

The particle sizes of the coking coals investigated during the last few years as part of the research program promoted by the West German Federal Minister for Research and Technology range between size consists 1 and 2. Even after just a few tests, it was discovered that the effect the particle size distribution has on the hydromechanical parameters of pressure loss and critical velocity is, for example, greater than the effect on the seam from where the coal was mined. These findings resulted in the so-called optimized particle size distributions. They are determined in the laboratory and whereby the optimization is heavily dependent on the type of coal.

Photographs taken with a scanning electron microscope (SEM) show that coal is a very heterogenous material whose structures (in coal petrography we speak of macenal composition) range from apparently homogeneous grains, so-called vitrite, via several intermediate stages to spongy formations, i.e. fusite. However, upon closer inspection, even the apparently homogeneous vitrite becomes inhomogeneous as is clearly demonstrated by SEM photographs. In order to answer the question of what happens with the coal particles during hydraulic transportation, for example how they are comminuted, the maceral composition of the coals was analyzed both before and after the simulated long-distance transportation tests. The maceral composition of the individual fractions of the particle size distribution had the following result. The fusite fractions of the coal are destroyed heavily by hydraulic transportation. This results in the size consist becoming finer. The enrichment of the fusite lies chiefly in the ultrafine range between 3 and 10 microns. The analysis also showed a shift of the inertinite for a German coking coal which had been transported hydraulically. A summary of the results of the Coulter investigations for the finest particle range of the coal both before and after transportation has been prepared. The transporting of medium coal suspensions over long distances depends to a very great extent on the proportion of fusite in the coal. The effect of the solids concentration on the comminution behaviour must also be taken into account.

The increase in the specific surface of the solid material is directly dependent on the abrasion which also affects the absorption capability of the coal. Thus, for instance, the specific surface of the coal was trebled in the example mentioned previously as was shown by BET measurements. It is not possible to go into more detail here about the effects that the increase in the specific surface has on the rheological behaviour of such suspensions. Yesterday, we heard something about this from Prof. Shook.

The influence of the particle size distribution is not only of interest for the pipelining, but it also has a strong bearing on the dewatering process. At present it is not economically possible to carry out large-scale mechanical dewatering of coal suspensions with a very high proportion of fine grains whereby the residual moisture is to equal less than 10%. Therefore, it is necessary to incorporate the dewatering of the coal into the overall system when optimizing the particle size. The system for the hydraulic transportation of medium coal suspensions must consist in offering a complete pipeline system comprising solids treatment, slurry preparation, pipeline transport and dewatering with optimum all-round economy. Seen in concrete terms this means: The size consists of the coal for hydraulic transportation must show up as almost straight lines in the RRSB diagram; the abrasion during transportation must be minimal; the end product must still be coarse enough to make mechanical dewatering economically viable. In order to explain this more clearly, I would like to describe one of the large-scale tests performed as part of our research project.

In May 1981, the pilot plant for hydraulic transport received 110 t of coking coal which was transported by usual means and which is used in the coking plants of Stahlwerke Peine-Salzgitter AG. In order to determine the hydraulic parameters about one-third of the coal was homogenized and then tested in the three circuits at the pilot plant.

The effect of the pipe diameter on the critical velocity was clearly observed. Looking at the specific power requirement, we were able to determine a relative minimum of about 43 weight % of solids in the 400 mm pipeline. After this initial test, two long-time tests were performed, each of which was to simulate transportation over a distance of 250 km. The concentration and the transport velocity in the 400 mm pipe were calculated on the basis of the optimum conditions which were determined during the initial test.

The abrasion resulting from this long-duration test was not so great, as was shown by the subsequent dewatering tests. The test described here was performed with centrifugal pumps which, with regard to the abrasion, means that the work was carried out under very unfavourable conditions, or in other words, if relatively good results can be obtained with centrifugal pumps, then the results with displacement pumps can only be better.

Krauss Maffei and Peine-Salzgitter AG developed in cooperation a new dewatering system together with the suitable machinery to solve the problems of piped coal-slurry. The most important points for the dewatering process are:

- minimal residual moisture in the solids
- minimal losses of solids in the water.

The process was taken for our dewatering tests. The classifying of the slurry is effected in a wing screen centrifuge. This new developed type of centrifuge works as a classifying and, at the same time, as a dewatering screen.

The slurry comes through a feed pipe into the centrifuge, which consists mainly of two rotors with differential speeds, and is distributed on rotating wing screens.

On these screens the slurry is classified in the overflow (coarse fraction) and the underflow (fine fraction). The coarse fraction is dewatered almost completely on the rotating wing screens.

After addition of flocculants, the underflow of this centrifuge (fine fraction) is dewatered directly in the continuous pressure drum filter.

The well-known filtercycle of this kind of filter is divided into a wet part, a drying part and the cake discharge.

After the dewatering process, the dewatered solid fractions are mixed together.

For our test with coal-slurry we got results in average residual moisture in the range of 9-16% by weight in the solids, depending on the PSD of the product. The recovery each time was +99,5%, the filtrate was nearly clear water.

The dewatered and mixed coal we gave back into the coke-ovens had an average residual moisture of 9,8% wt. The coke produced from this hydraulically transported coal is as good as the coke produced from normal transported coking coal.

Comment on Paper by Klose

Mr. Mikhail noted that one problem faced in Canada is that the Japanese, who are the purchasers of the coking coal eligible for transport by slurry pipeline, set a limit on the content of fines. It was asked if fines really influence coking properties and it was agreed they do - they aid hydraulic properties but harm coking properties. It was observed that irrespective of whether or not increased fines really degrade coking properties the Japanese don't want them because of safety reasons.

Wachmann: Environmental Evaluation and Mitigation

C. Wachmann, Environment Canada, Hull, Quebec

Canadian experience with slurry pipelines has been mostly related to the disposal of mine tailings. Since the days of the first pipelines, public awareness of the potential impact of slurry pipelines has grown tremendously. Projects are now scrutinized for environmental impact much more closely. To a large extent, industry seems to have accepted pollution control costs as necessary to meet public expectations.

In Canada, natural resources come under provincial jurisdiction. The environmental impact of a resource development is assessed by the provincial government.

The federal government has jurisdiction over resources on federal lands, including the Yukon and Northwest Territories, and over resources in national parks. In cases where federal or provincial jurisdiction is not clear, both levels of government may act jointly.

Environment Canada provides advice to industry and provides a conservation service.

- Disposal of waste water from the mine wash plant.
- Water sourcing for the main pipeline.
- Disposal of slurry water.

- Pipeline routing through national parks, river crossings, over permafrost.
- Operation of slurry preparation plants, pump stations, and marine terminals.
- Selection of the marine terminal site.
- Noise, dust pollution.

In each of these areas, there is a need for environmental stabilization, rehabilitation, and monitoring.

The Role of Environment Canada:

. Prevention:	siting, planning, front-end work, assessment of environmental impact.
. Mitigation:	mitigation of unavoidable impacts, in conjunction with industry; rehabilitation of areas as quickly as possible.
. Emergency Planning	
. Monitoring:	to verify with industry that procedures are effective, and to determine if predictions of impact were accurate.

Mr. Wachmann summarized the major elements of the environmental review process administered by Environment Canada. A guide to the process is available from Mr. Wachmann.

Environment Canada's direction in the near term will be:

- to complete a report on the coal environmental interface;
- to develop environmental criteria for coal slurry pipelines;
- through the workshop to cooperate with industry, provincial governments, and internationally in the development of good environmental practices.

Wiedenroth: Comments on the Environemental Impact of Slurry Pipelines

Herr Prof. Wolfgang Weidenroth, University of Paderborn, Germany

Germany has five administrative acts which relate to coal transportation.

The two major environmental issues are pollution and distortion of the landscape. Every industrial activity causes some pollution of the air, water, or in the form of noise. The German public has become very sensitive to these issues. For example, we have court cases over the noise of conveyor belts in residential areas, and problems with dust from mine tailings.

Hydrotransport is environmentally attractive because it minimizes distortion of the landscape.

Lawrence: Personally, I am very concerned about the rapid growth of the federal and provincial governments since World War II. The cost of the environmental review process has skyrocketed. Hearings that used to take months now take several years.

Many project initiators find the whole process extremely frustrating. As a result, many projects are allowed to die before they get past the environmental review phase.

We have to re-evaluate the advantages versus the costs of environmental regulation. The costs may be making us non-competitive on world markets. There is a real need to reduce the time and delays associated with the review process.

Warfe: I realize it can be very frustrating, but how can one properly assess the cost of not regulating? How do you assess the value of a lower quality of life? What we really need is to make our regulations more practical. Industry should continue to lobby for this.

Wachmann: Environmental planning is very necessary, especially because of the size of the megaprojects we are contemplating today. Megaprojects can have mega-environmental impacts. Besides, if the cost of preventing pollution is not dealt with by the company, the cost of the clean-up must be borne by the public through taxes. We must also protect other resources in addition to the one being developed, and safeguard our quality of life. Environmental concerns must be dealt with when a project is initiated - not after it is built.

Closing Remarks

Mr. J.J.O. Gravel, Transport Canada, thanked all participants for making the workshop such a success. He expressed the appreciation of all those in attendance to the delegation from the Federal Republic of Germany for coming so far to share their knowledge and insights in this field. He mentioned that a meeting of the national delegations was planned to develop recommendations and set priorities for future cooperative R&D. He also mentioned that the proceedings of this mini-workshop would be circulated and invited attendees to submit their comments. Mr. Gravel then declared the workshop closed.

International Participants

Mr. Thomas C. Aude, Pipeline Systems Inc.,
Orinda, California, U.S.A.

Herr Felix Fiseni, Technischer Uberwachungs-Verein Rheinland e.V., Projektbegleitung
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Herr Prof. Franz Joseph Geller, Fachhochschule
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Herr Dr. Ewald Gödde, Pipeline Engineering
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Herr Reinhard Klose, Stahlwerke Peine-Salzgitter AG
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Herr Friedhelm Stephan, Salzgitter Industriebau
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Herr Prof. Wolfgang Weidenroth,
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CANADIAN/GERMAN COAL SLURRY PIPELINE TECHNICAL WORKSHOP

Canadian Industry and Scientific Participants

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Dr. Randall G. Gillies, Research Scientist,
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Mr. K. Gomyo, Senior Staff Engineer
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Dr. W.H.W. (Bill) Husband, Head, Engineering Division,
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Mr. Stevenson, Vice-President, Business Development,
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CANADIAN/GERMAN COAL SLURRY PIPELINE TECHNICAL WORKSHOP

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Energy, Mines and Resources Canada,
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Mr. E. Weinberg, Director,
Freight Services,
Canadian Transport Commission

CANADIAN/GERMAN COAL SLURRY PIPELINE TECHNICAL WORKSHOP

AGENDA

SESSION ONE

9:00 - 12:00

Monday, September 27

A. Welcome and Opening Address

B. Coal Transportation - The Economic Alternatives
Aude/Comments - Klose

C. Consideration of Pipelines for solids as a Link
in Transport Chains - Fiseni

D. Alberta Coal Slurry Pipeline Study 1981
Including an Economic Assessment Opposite Rail
Transportation - Rabb/Bassett
Comment - Klose/Gödde

LUNCHEON BREAK

12:00 - 14:00

SESSION TWO

E. Coal-In-Methanol Slurries - Rutherford
Comment - Gödde

F. If CDN Suggestion Accepted by FRG
Experience on Coal in Methanol Slurry and
Gödde's Project Report March 81 - Gödde

G. Capsule Pipelines - Roehl
Comments - Gödde

H. Dense Coal Slurries - Shook
Comments - Klose

CANADIAN/GERMAN COAL SLURRY PIPELINE TECHNICAL WORKSHOP

AGENDA

SESSION THREE

TECHNOLOGY AND EVALUATION

Tuesday, September 28

A. Pilot Scale Capability of Solids Pipeline Testing - Husband
Comment - Wiedenroth/Geller

B. Laboratory Tests in Simulating Pipeline Transportation - Wiedenroth/Klose

C. Selection and Design of Slurry Pumps - Young
Comment - Stephan

LUNCHEON BREAK

12:00 - 14:00

SESSION FOUR

D. Problems in Separation of Solids From Liquids

E. Prediction of Size Degradation of Coarse Coal During Slurry Pipeline Transportation - Mikhail
Comment - Geller

F. Effects on Coking Properties of Metallurgical Coal by Pipeline Transportation - Klose

G. Environmental Evaluation and Mitigation - Wachman
Comment - Wiedenroth